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**LOAD CAPACITY CONSTRAINT REGULATION
(LCCR)**

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Abstract: The aim of the model is the comparison of flow regulations subjected to different kinds of constraints : <ul style="list-style-type: none"> ➤ Sector load constraints ➤ Sector capacity constraints ➤ Simultaneous sector capacity and load constraints. The model shows that the regulation based on load constraints is the most efficient in terms of flight delays. The results of the double constraint regulation (capacity plus load) do not differ very much of those obtained by the regulations based on the sole capacity constraint. The reason is that the capacity constraints are much more restricting than the load constraints. The prototype has been implemented as a highly parameterised simulation tool that should be well fitted to study, among other topics, the impact of various flight priority definitions. For the time being flow management operational staff has not yet validated the prototype.						

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Load Capacity Constraint Regulation

L C C R

by

J. DEGRAND

SUMMARY

More and more research is done in order to solve the problem of the ever increasing traffic delays in the European Airspace. The present study tries to investigate if an improvement can be achieved by changing the basic constraints on which the current regulation techniques are built on.

The currently used CASA (Computer Assisted Slot Allocation) by the CFMU in Brussels is based on capacity constraints. This study tries to show that a regulation based on load constraints is more efficient.

The sector load is the number of aircraft simultaneously present in the sector at a given moment. The sector capacity is the maximum number of aircraft allowed to enter the sector in one hour.

Since the load constraint uses more efficiently the available airspace (the traversal of a sector by a plane is much less than one hour, duration that lies at the basis of the capacity constraint) the total delay should decrease.

The results, which are not yet validated by the operational staff, confirm the previous hypothesis. The penalisation in terms of total delay and number of delayed flights is effectively much lower than in the case of the capacity constraint regulation.

If this new concept is validated many studies can be done in order to improve the current flow management. One of the first one should deal with various flight priority implementations. This could be done in parallel with the current priority study based on the capacity constraint regulation.

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INTRODUCTION

This report discusses a fundamental change of the flow management procedures used today. By my knowledge it is strictly outside the orderly routine development of Air Traffic Flow Management (ATFM) as planned in the current formalised programs of Eurocontrol, The European Union and other ATC organisations. For that reason, the formal disclaimer normally appearing on the title page of all EEC reports is repeated and amplified here in bold type for emphasis.

**This report represents ONLY the opinion of the author.
It does not IN ANY WAY represent the Official policy of the Agency.**

Furthermore operational staff does not yet validate the results of the prototype.

Lastly, although the author has benefited from informal discussions with Air Traffic controllers and Flow controllers over the past twenty nine years, he has never been, is not and could never be, neither an Air Traffic controller nor a Flow controller. Thus, due to a lack of formal co-operation with operational staff, (except the sporadic help of one flow controller of the CFMU, which, by the way, was very efficient) the study could only take partly into account the actual day-to-day problems the active operational staff faces daily.

So, the ideas presented here are entirely personal, and the author is regretfully aware that they have not yet raised any interest among the operational staff.

The report is divided in three parts. The first part is an explanation of the background, the aim, the implementation and the provisional results of the prototype. It is written in common language and is due to the author.

The second part is a rather technical account composed by E. Mercier, engineer of Cosytec (Complex System Technology) who implemented the prototype.

The third part is the User's Manual.

PART ONE

L C C R

LOAD CAPACITY CONSTRAINT REGULATION

Abbreviations

ANM	Atfm Notification Message
AO	Air Operator
ATC	Air Traffic Control
ATFM	Air Traffic Flow Management
CASA	Computer Assisted Slot Allocation
CFMU	Central Flow Management Unit
COSYTEC	Complex Systems Technology
ECAC	European Civil Aviation Conference
EEC	Eurocontrol Experimental Centre
FMP	Flow Management Positions
IFPS	Integrated Initial Flight Plan Processing System
LCCR	Load Capacity Constraint Regulation
SRS	Standard Routeing Scheme

1 BACKGROUND

1.1 ATFM (Air Traffic Flow Management)

The severe congestion problems increasingly experienced since the mid 1980's by Air Traffic Management (ATM) systems have directed much current attention toward Air Traffic Flow Management (ATFM).

Congestion occurs whenever the capacity of one or more elements of the ATM system (airports, terminal-area, en-route sectors) is exceeded by demand over a period of time. Thus congestion is mostly associated with peak traffic hours of the day, peak travel times of the year and periods of adverse weather conditions.

In the long run (over periods of 10-20 years) congestion may be alleviated by means of capacity improvements attained through the construction of additional runways and airports or through advances in ATM technology and procedures.

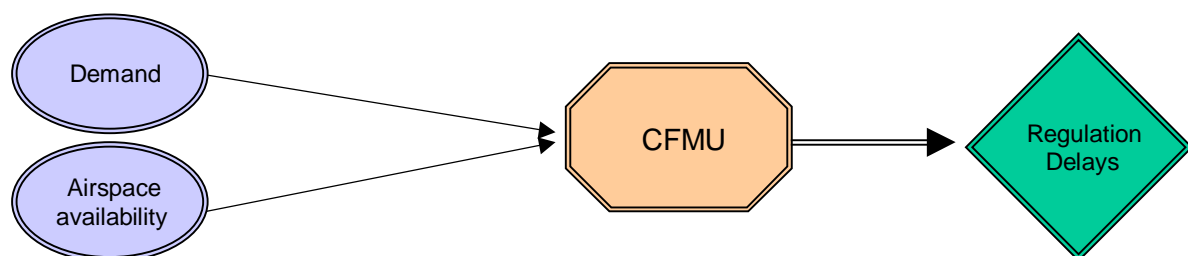
In the medium term (six months to a year) "demand management" measures, such as slot assignment at busy airports or use of congestion-pricing at such airports, may also be helpful.

On a short-term basis i.e. for any given levels of demand and for any given ATM system capacity, ATFM provides the only approach for reducing the costs due to air traffic congestion. Thus, ATFM's objective is to manage dynamically air traffic demand with the available capacity of airports and airspace sectors, on a day-to-day basis, in order to minimise the cost due to congestion.

1.2 CFMU (Central Flow Management Unit)

In this context the ECAC (European Civil Aviation Conference) asked Eurocontrol in the beginning of the 90's to provide an air traffic flow management service throughout the airspace of the 35 ECAC Member States. This unit, CFMU, became fully operational in the Spring of 1996, replacing the five regional flow management units previously operated by national administrations.

The objective of the CFMU is to complement ATC (Air Traffic Control) in implementing a regulatory and smoothing mechanism in order to avoid overloads and to maximise the most efficient use of the airspace by providing dynamic flow management. This regulatory mechanism consists in imposing ground delays on flights crossing overloaded sectors in order to eliminate the congestion.



To meet the objective of balancing demand and capacity the CFMU undertakes flow management in three phases. Each flight will usually have been subjected to these phases, prior to being handled operationally by ATC.

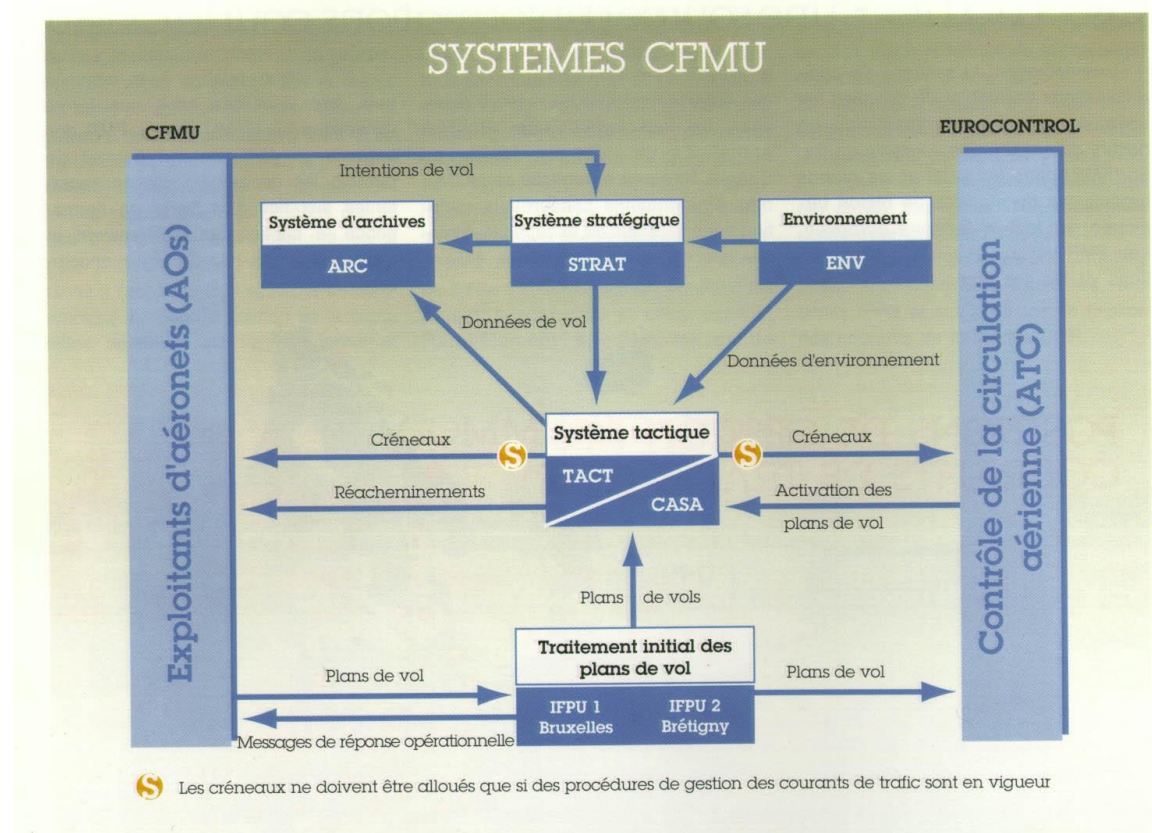
Strategic ATFM activity takes place during the period from several months until two days before a flight. A strategic demand forecast initiates the Standard Routeing Scheme (SRS) which is a structure of mandatory European air routes in order to ensure maximum use of the available airspace.

Pre-tactical ATFM activity takes place during the two days before the day of operation. Based on the strategic forecasts, the information received from the Flow Management Positions (FMP) at every air traffic control centre in Europe and the CFMU statistical data, the Atfm Notification Message (ANM) for the next day is prepared. It defines the tactical plan for the next (operational) day and informs aircraft operators and air traffic control units about the ATFM measures that will be in force in European airspace on the following day.

Tactical ATFM is the work carried out on the current operational day. It includes the allocation of individual aircraft departure times, re-routings and alternative flight profiles.

The IFPS (Integrated Initial Flight Plan Processing System) is the main source for the CFMU demand database. All flight plans within the IFPS airspace are sent by the air operators to the IFPS, which acknowledges receipt, processes the data, stores it in the CFMU data base and sends the information to the air traffic control units which will be concerned with the flight.

CASA (Computer Assisted Slot Allocation) is the currently used regulation algorithm. Without going into details let us say that it is based on capacity constraints of the sectors. The airspace is divided in three dimensional volumes called sectors. For each sector a controller is in charge and this controller can handle a maximum number of flights per hour. This number is called sector capacity. If this capacity is exceeded by the demand the sector will be regulated by giving entry slots to the flights concerned. In order to satisfy these entry slots the flights are delayed on ground.



2 LCCR

The aim of the LCCR prototype is to investigate whether regulations based on load constraints would be less penalising in terms of delays than regulations based on capacity constraints, as the currently used CASA algorithm is implemented.

Remember : The sector load at a given moment is the number of aircraft simultaneously in the sector at that moment.

The sector capacity at a given moment is the maximum number of aircraft that are allowed to enter the sector in one hour.

The aim of the LCCR prototype is to compare the results of regulations based either on sector load constraints, sector capacity constraints or constraints on both sector load and capacity.

The idea behind this work is based on the fact that the sector load unit used by an aircraft is blocked only during the duration of the flight across the sector while the capacity unit is blocked during a fixed period (usually an hour). Since the duration of the traversal of a sector is far less than an hour the sector resource is more efficiently used by a load regulation and consequently the penalisation in terms of delays should be decreased. Furthermore, the load is a more realistic concept for the controller since it represents the number of aircraft he has on the screen and he has actually to take care of simultaneously.

IMPLEMENTATION

The sector load constraint regulation is treated as a standard activity-resource problem for each sector. The resource is the maximum sector load. The activity is the flight traversing the sector. During the traversing time (plus the co-ordination time between the previous and the current sector) it consumes one unit of the resource. Thus, the total number of activities is the number of flights times the number of sectors they cross. The problem is solved by the cumulative constraint concept implemented in the Chip software.

The sector capacity constraint regulation is implemented as follows : at any given time t the number of aircraft having entered the sector during the period $[t-60 \text{ min.}; t]$ must not exceed the capacity currently used at time t .

The following implemented functions are common to the three different kinds of regulation.

FUNCTIONS

CONSTRAINTS

- Load-capacity constraints on sectors.
- Among the daily flights a certain number is regulation exempted, i.e. these flights can not be subjected to any delay.
- For round trip flights the regulated time between the arrival time of the first leg and the departure time of the second one must not be less than the corresponding estimated time. In other words, the delay of the first leg is transferred to the second one.
- The order of the departure time of two flights having the same itinerary (same departure and arrival airports) can only be reversed if the difference of the reversed regulated departure times does not exceed a certain amount (input parameter). This is the so-called equity criterion.

All these constraints, except the second one, can be neutralised by an input parameter.

PRIORITIES.

For simulation purposes certain priorities can be chosen :

- Round trip flights : If the first leg has a delay greater than a threshold (input parameter) a priority is given to the second leg in order to minimise an additional delay.
- Type category : Following the general heuristics (see later) if two flights have the same value of their priority function the plane, the type of which belongs to the highest category priority, is placed first.

Via input parameters these priorities can be chosen or not.

RELAXATION

The basic idea is that the whole demand (all the filed flight plans) must be satisfied. Thus, the constraints on the domain variables affecting regulation, i.e. sector resources (capacity, load)¹, flight delays (with one exception), must be SOFT constraints. (In the current release of the prototype the rerouting alternative is not foreseen). The relaxation of these constraints are implemented according to the following hierarchy :

- a) If, after setting the constraints, no solution is possible, even with the maximum flight-delay relaxation, the sector constraints of the overloaded sectors are relaxed, i.e. the capacity or the maximum load is increased by one unit or more than one unit. Once the system is feasible, the regulation exempted flights are set.
- b) For all the other flights, if there are still congested areas, relaxation of the maximum accepted delay is enforced until a fixed limit is reached. If there are still overloaded sectors :
- c) Relaxation of the constraints of the most congested sectors (according to a congestion priority function) until all the flights pass. If the maximal relaxation, fixed by input parameter, is not high enough the solver finds no solution.

All these relaxation procedures are executed in several steps. The amplitude of each step and the limit of the flight delay relaxation are defined via input parameters.

NOTA BENE : The relaxation respect the equity and priority criteria.

HEURISTIC

The number of daily flights over Europe lies between 20.000 and 27.000. About 2.000 sectors are concerned. The quality of the regulation depends heavily on the heuristics chosen:

The exempted flights are placed first. For all the other flights a priority function is computed. It is an increasing function of the degree of congestion of all the sectors the flight crosses. The flights are placed in descending order of this function. Exception : The two legs of a round-trip flight are treated together if the round trip priority has been chosen by input parameter. It is the same for the equity constrained flights if the equity trigger has been enabled.

¹ The capacity and the maximum load are fixed input values. For constraint computing purposes they are transformed in domain variables the domain of which are limited by the fixed input value and the maximum relaxation value.

DETAILS

1) SECTORS - COLLAPSED SECTORS

A sector is open individually during certain periods of the day. For the rest of the day it belongs to collapsed sectors that regroup several individual sectors. A sector is open 24 hours a day, either individually or by means of collapsed sectors to which it belongs.

2) REGULATION PARAMETERS

- a) DELAY : Each flight plan contains a maximum delay that should not be exceeded. This delay is a domain variable taking its numerical value between 0 and maximum delay. The delay constraint is soft except in the case of exempted flights (maximum delay = 0).

Each flight has its individual maximum delay. But, except the exempted flights, the numerical value of it can be overwritten by a global value defined by aircraft type category.

- b) LOAD - CAPACITY : Each sector/collapsed sector has an individual maximum load and capacity for each open period. The maximal load depends on the capacity. A basic load value (input parameter) corresponds to the lowest capacity during the day. For one unit capacity increase the corresponding maximal load is increased by 10%. Nevertheless, for simulation purposes the value of every individual maximal period load can be modified independently of the capacity.

3) ROUND TRIP FLIGHTS : Two flights are considered being the first and second leg of a round trip flight if :

- The callsigns are the same except the last digit that is increased by one for the return flight.
- The aircraft types are identical.
- The departure and arrival airports are swapped.
- A predefined fixed time period (input parameter) has to elapse between the arrival of the first leg flight and the departure of the return leg. Thus, a delay encountered on the first leg will be propagated to the return leg.

4) CO-ORDINATION : During the whole traversal of a sector a flight is under the control of the air traffic controller responsible for this sector. But the activity of the controller starts x minutes before the flight enters its sector. These x minutes are called the co-ordination time. During this time the control remains under the responsibility of the previous sector but the controller of the next sector has to take the flight already into account in order to prepare the insertion of the flight into the traffic of the other flights traversing the sector at the same period. Each sector has its own individual co-ordination time. But an overall unique numerical value (input parameter) can overwrite the individual values. The co-ordination time is added to the duration of traversing of the sector by the aircraft in order to fix the activity duration time.

5) OVERLAPPING FLIGHTS : Flights, the estimated departure time takes place on the eve of the currently studied day, are not taken into consideration.

- 6) INPUT DATA MODIFICATIONS : Before the Solver is launched there is an easy access to all the input data, flight plans, environment, airports, aircraft types, type category. In order to allow consecutive tests some of these data can be modified on-line :

- Maximum flight delay.
- Aircraft type.
- Estimated departure time of a flight.
- Maximum sector load and capacity .

LCCR deals automatically with induced input data modifications due to a primary modification. For instance, the estimated departure time update induces the same update for the other estimated times of a flight plan.

- 7) HARDWARE : The prototype has been implemented on a Hewlett-Packard Kayak PC (bi-processor, 2* 450 MHz, 384 Mb) under Window NT.

SHORTCOMINGS

The main shortcomings of the current release of the prototype are :

- 1) LCCR takes into account only those flights whose the estimated departure time is inside the 24 hour window of the studied day. Thus, the transatlantic flights taking off in the US before midnight (GMT) and entering the European airspace early in the morning are not considered. The impact on the regulation results is difficult to foresee.
- 2) Bunching. The sector load and capacity parameters are defined per time period. It may happen that during a period a sector presents no difficulty and the corresponding parameters are put to "infinity". If, during the previous period, the sector was regulated (constraint parameters different from "infinity") it may happen that a certain number of flights that, according to their estimated entry time should have entered the sector during the regulation period, have a delay that does not allow their entry into the sector before the end of the regulated period. These flights will enter all together the sector at the same time at the beginning of the period with infinite load and capacity. This phenomenon is called bunching. This peak of traffic should be smoothed by allotting entry slots in the sector. This feature is not implemented in the current release. The impact on the results is unpredictable.
- 3) Curfew. Due to a lack of information , currently, the curfew is considered as a period of non availability, i.e. after this period the airport is operational. Since LCCR deals only with the 24 hours of a day a night curfew is considered finished at midnight. Thus, planes can arrive at any time after midnight, which, of course, is incorrect.
- 4) Due to lack of power and core of our hardware the simulation of the combined load and capacity regulation could not be done. But, a priori, we expect that the result should not differ very much from that obtained with capacity constraints. This is due to the fact that the capacity constraints are much more restricting than the load constraints.

RESULTS

Since the prototype and the results are not validated by operational staff we will make only two short comments on the table (page 11).

- 1) Capacity regulation versus load regulation : The total delay is much higher in the case of the capacity regulation. Since the number of delayed flights does not vary in the same proportion the average delays are much higher. Furthermore, the number and the amount of long delays increases significantly. It is the same for the number and the degree of relaxation on flights and sectors.
- 2) Load regulation : The sensitivity of the maximum sector load is high for the total delay and the number of delayed flights. The average delays vary less. It is the same for the distribution of the delays.
- 3) Graphs : Graph 1) to 6) represent the traffic traversing the sector EDYMURW on the 18th of June 1999. Red corresponds to the capacity curve, green to the load curve. At time t the capacity curve indicates the number of flights having entered the sector between t and $t-60$ minutes. The load curve represents the number of flights being simultaneously in the sector at time t . The light grey curve indicates the number of flights the delay of which lies between 15 and 35 minutes. The darker grey curve represents the flights the delay of which exceeds 35 minutes.
 - Graph 1) represents the demand. The capacity limit is 45; the load limit is 13. The sector is regulated during the two periods: 4.00- 5.30 and 12.00-21.00
 - Graph 2) shows the capacity demand curve and the modifications after a capacity regulation (full red).
 - Graph 3) shows the same than graph 2) plus the impact of the capacity regulation on the load curve.
 - Graph 4) and 5) give the curves corresponding to load regulation.
 - Graph 6) gives an overall view of the total delay distribution.

3 CONCLUSION

As said before the previous results are still provisional. They were obtained in giving the same numerical value to individual parameters, maximal basic sector load and maximal accepted flight delay. To improve the results and make them closer to reality the values of these parameters have to be adapted to the individual sector and flight situations. This work can only be accomplished by experienced operational staff.

Furthermore, the shortcomings mentioned before should be dealt with, in particularly the integration of the airport regulations that are not yet covered. Many other improvements defined in close collaboration with operational staff will hopefully be implemented later.

Nevertheless, despite the previously mentioned shortcomings, we can state by now that traffic flow regulation based on sector load constraints is much more efficient in terms of delays than regulation based on sector capacity constraints.

4 COMPLEMENTARY STUDIES

If the new concept is going to be validated the main further studies proposed are :

- Add airport regulation to the current airspace regulation.
- Add to the current regulation based on flight delays the alternative of rerouting.
- Implement various priority schemes for simulation purposes, among them a city to city flow priority.

5 ACKNOWLEDGEMENTS

I must hereby acknowledge my debts to two persons. Without their help the prototype could not have been implemented as it is today.

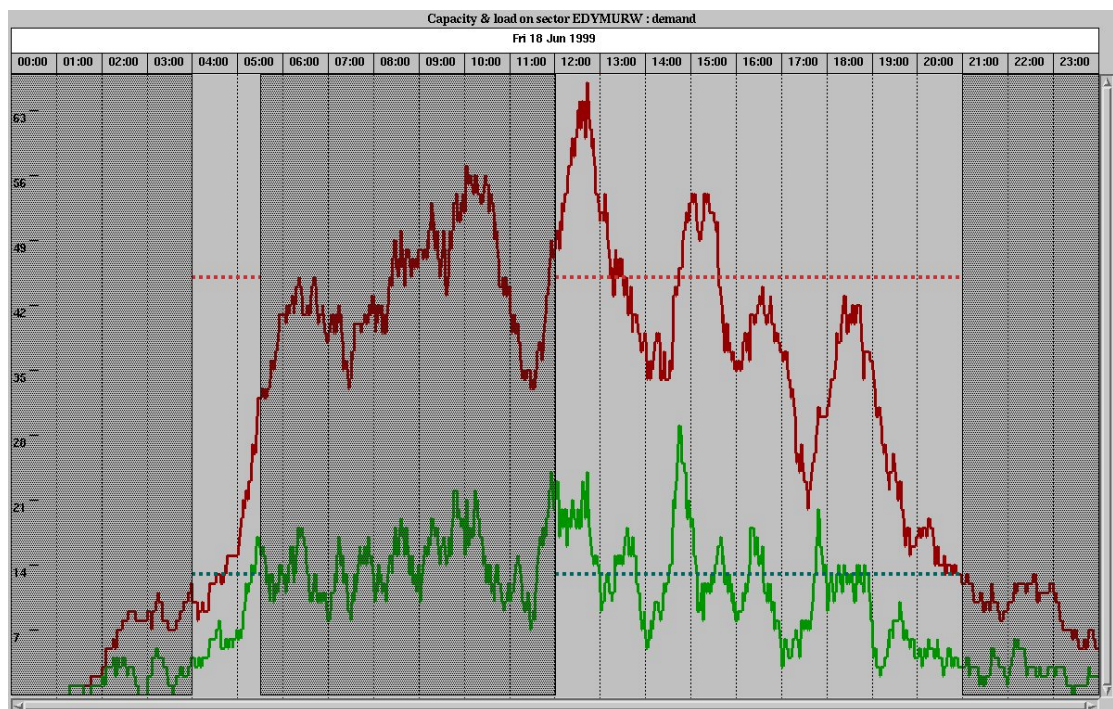
The current Director of Eurocontrol Experimental Centre, M. J.-M. Garot, not only gave me the freedom to develop a new concept. Through his personal and direct intervention I could have the necessary financial support.

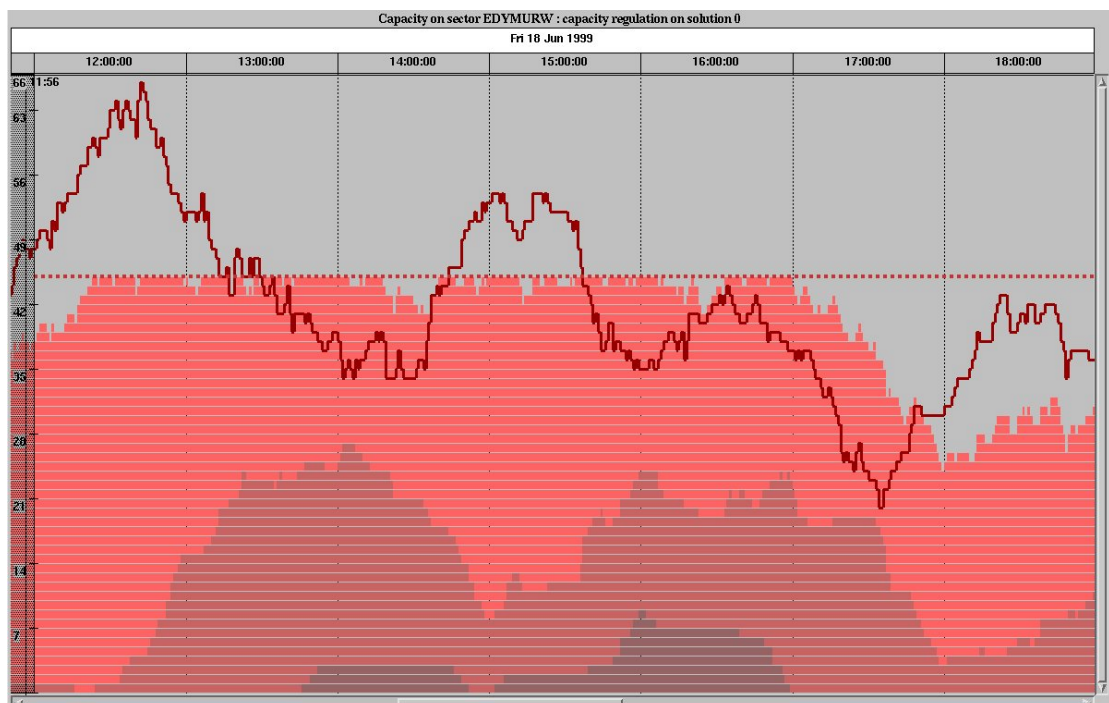
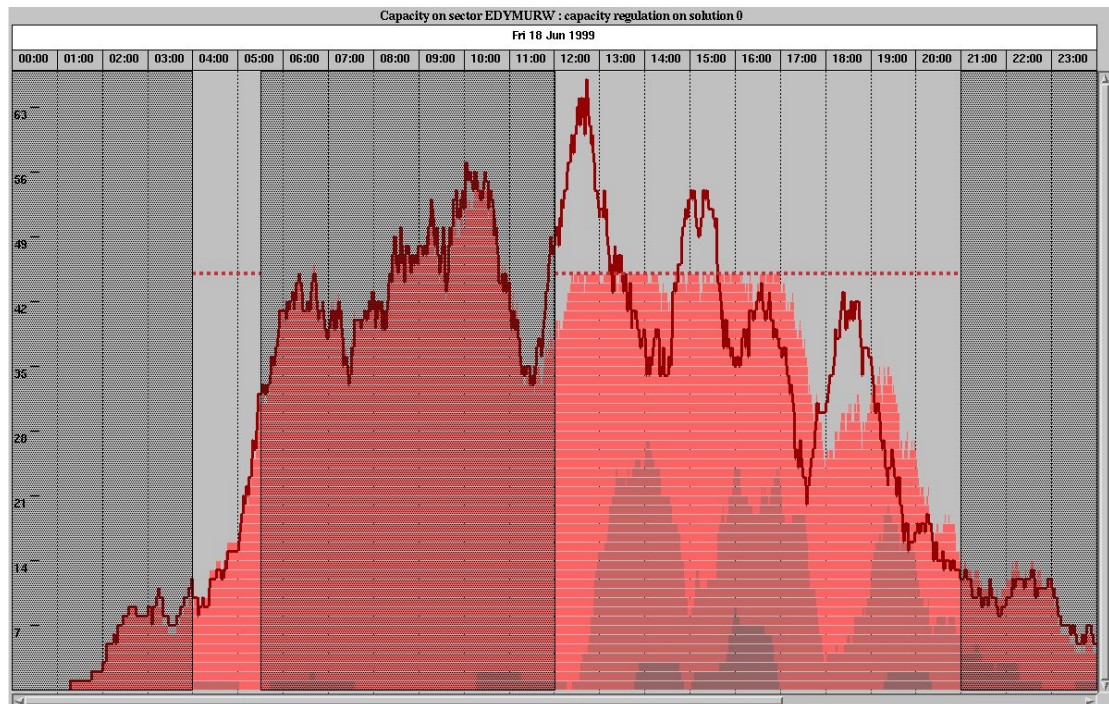
M. G. Ranc, active flow controller at the CFMU in Brussels, gave me a very important operational help through several one-week missions at Brétigny. He updated the environmental CFMU input data and, thanks to his advice, the current prototype can take into account, at least partly, the desiderata of the operational staff.

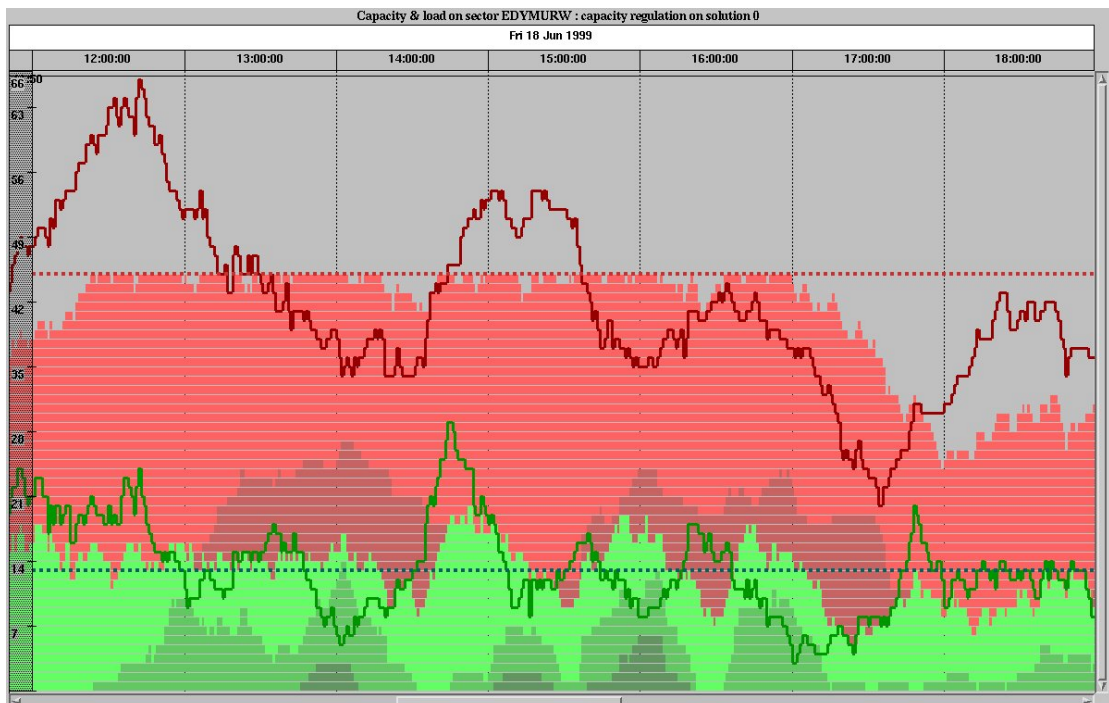
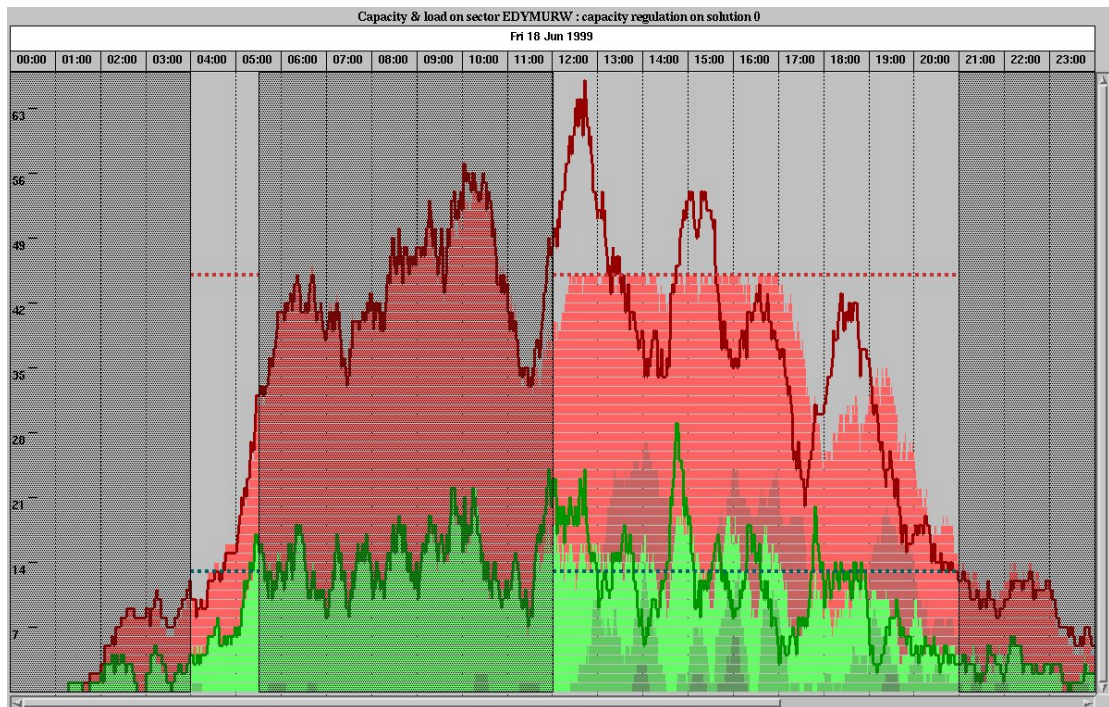
The following results are relative to the traffic of the 2nd July 1999. The number of flights involved is 23.853. The maximum accepted delay is 180 minutes.

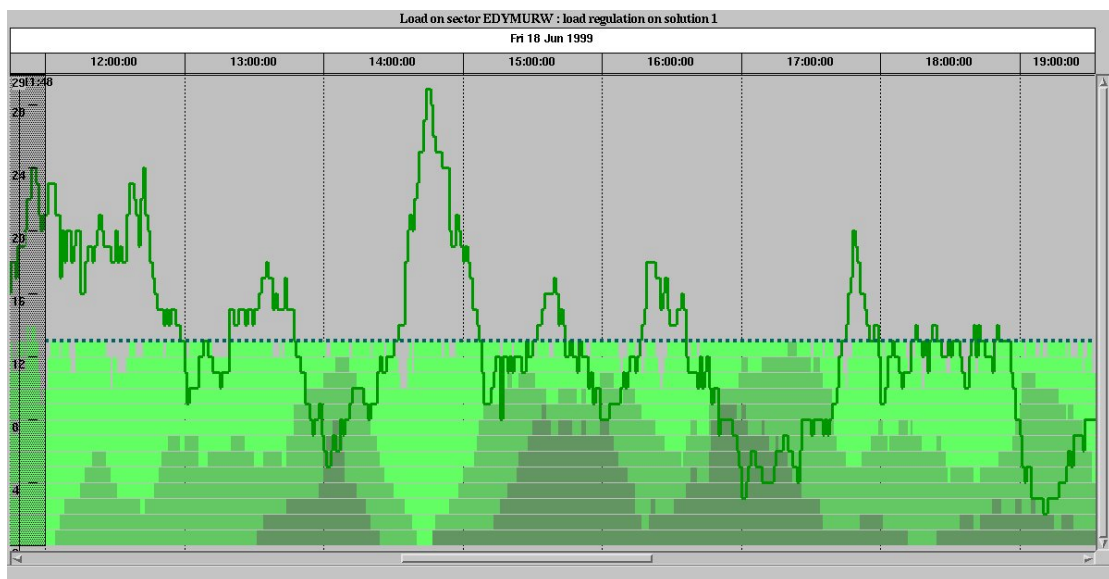
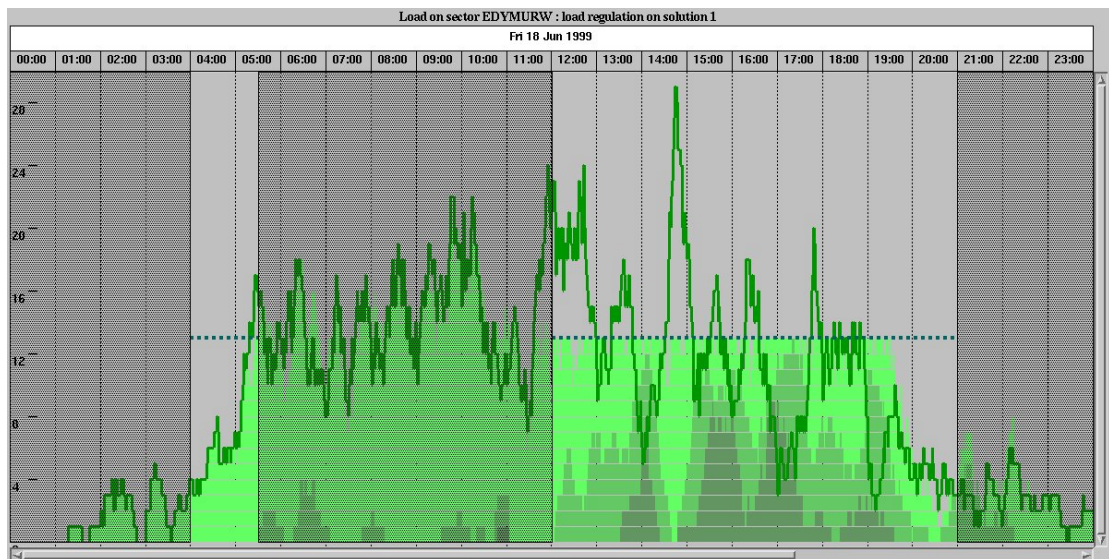
REGULATION TYPE	TOTAL DELAY (min)	DELAYED FLIGHTS	MAX. DELAY (min)	AVERAGE DELAY (min)	AVERAGE DELAY per DELAYED FLIGHT (min)	DELAYED FLIGHTS with a delay < 15 min + TOTAL DELAY	IDEM 15<delay<45 min	IDEM 45 min <delay	RELAXED FLIGHTS + MAX. RELAXATION	RELAXED SECTORS + MAX. RELAXATION
LOAD 13	127976	3727 (15%)	359	5.4	34	1369 (37%) 10131 (8%)	1435 (38 %) 38223 (30 %)	923 (25 %) 79622 (62 %)	26 (0.11 %) 99 %	1 (0.05 %) 100 %
LOAD 14	83931	2744 (11%)	193	3.5	31	1124 (41%) 8298 (10%)	1069 (39%) 27164 (32%)	551 (20%) 48469 (58%)	9 (0.04%) 7 %	1 (0.05%) 86 %
CAPACITY	245872	3751 (16%)	359	10.3	66	550 (15%) 4229 (1.7%)	1164 (31%) 33716 (14%)	2037 (54%) 207927 (85%)	148 (0.62%) 99 %	59 (3%) 100 %

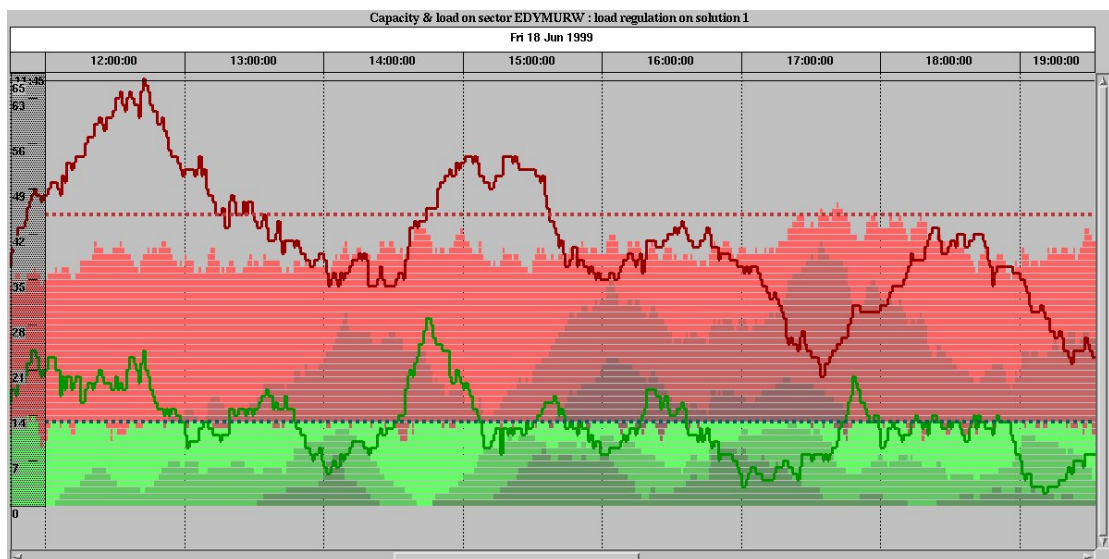
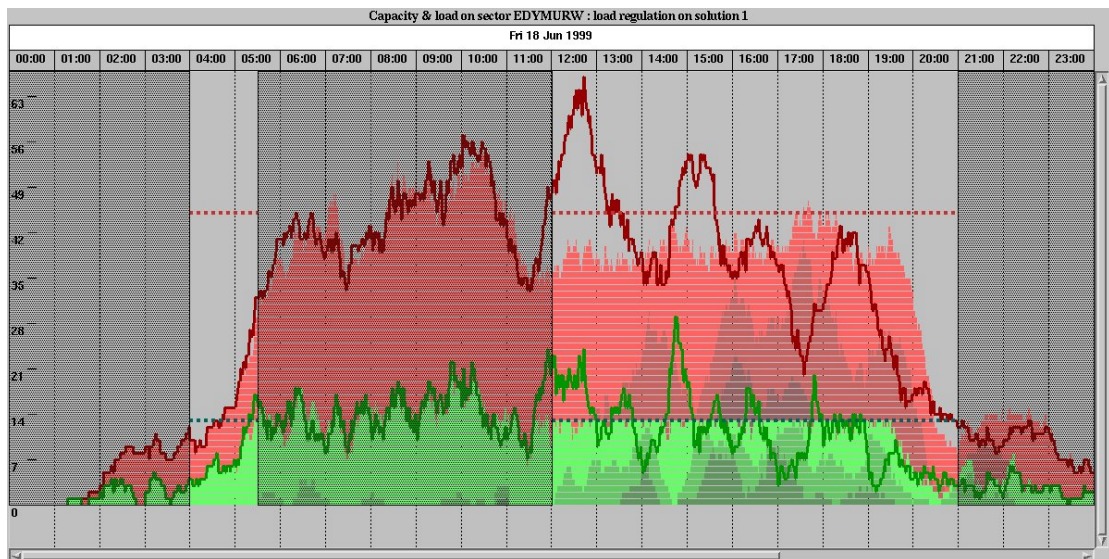
T A B L E

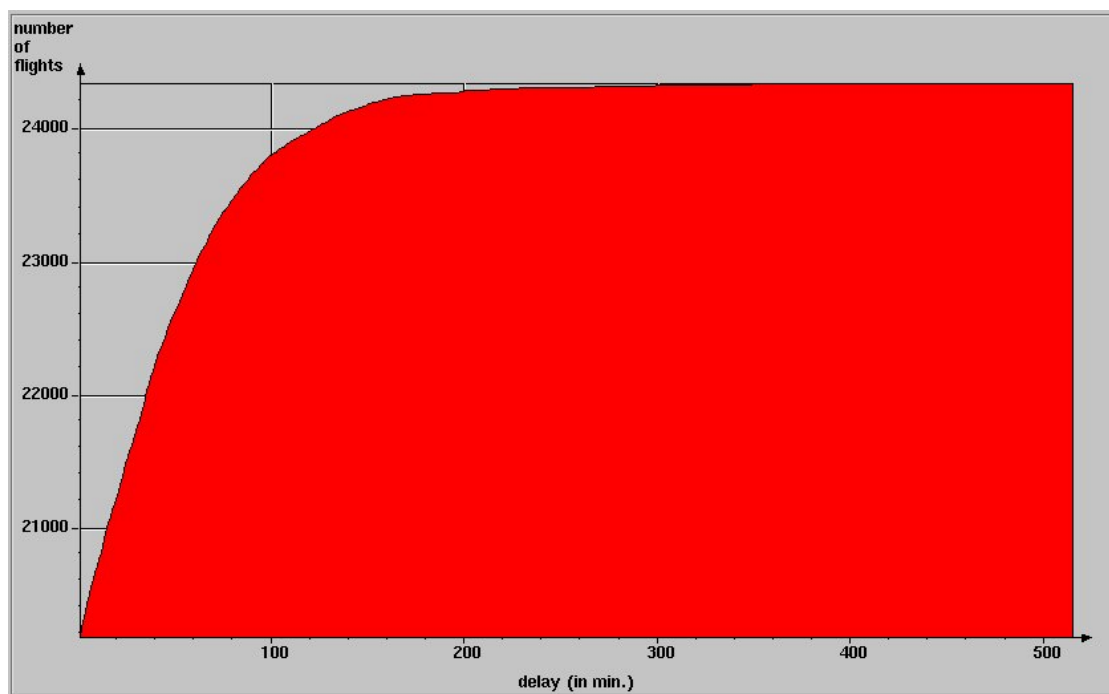
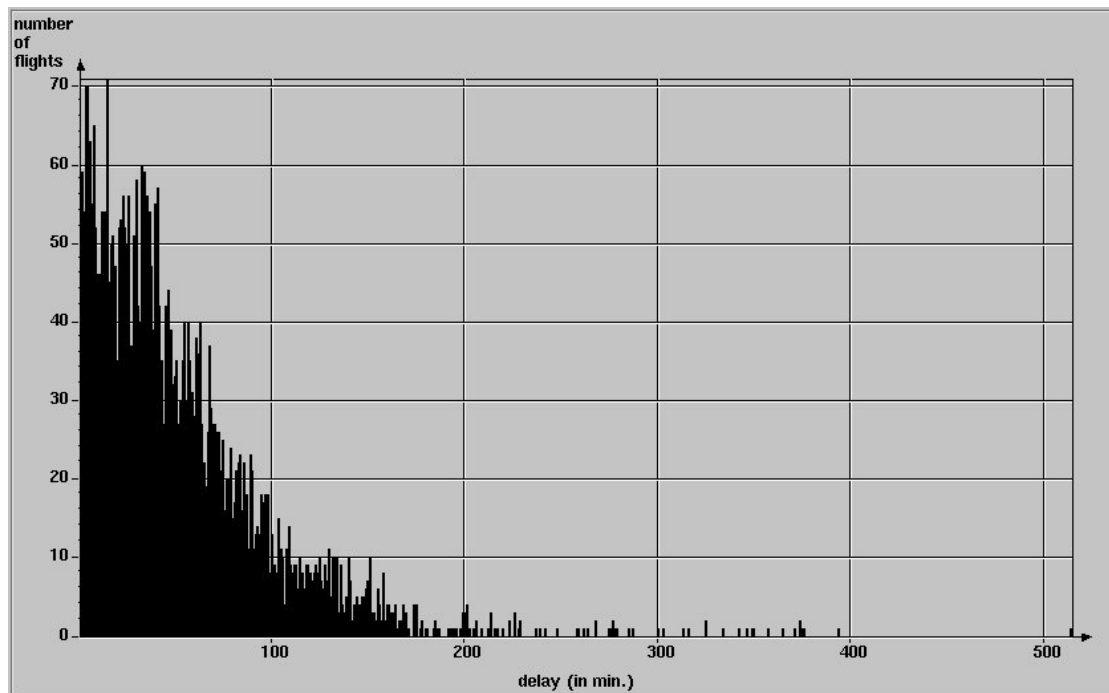












VERSION FRANÇAISE DU SOMMAIRE, DE L'INTRODUCTION ET DES CONCLUSIONS
FRENCH VERSION OF SUMMARY, INTRODUCTION and CONCLUSIONS

Load Capacity Constraint Regulation

L C C R

par

J. DEGRAND

SOMMAIRE

De plus en plus d'études traitant du problème des délais de route des vols dans l'espace européen voient le jour. L'étude présente cherche à améliorer la gestion des flux aériens en introduisant un nouveau concept des contraintes de base.

L'algorithme CASA (Computer Assisted Slot Allocation) utilisé par la CFMU à Bruxelles est basé sur des contraintes de capacité. Cette étude essaye de montrer qu'une régulation basée sur des contraintes de charge est plus efficace.

La charge d'un secteur est le nombre d'avions présents simultanément dans le secteur à un instant donné. La capacité d'un secteur est le nombre maximal d'avions pouvant entrer dans le secteur en une heure.

Comme la contrainte de charge utilise plus efficacement l'espace disponible (la durée de traversée d'un secteur par un avion est très inférieure à une heure, durée qui est à la base de la contrainte de capacité), le délai total devrait décroître.

Les résultats, qui, je le rappelle, ne sont pas encore validés par les opérationnels, confirment cette hypothèse. La pénalisation en termes de délai totale et de nombre d'avions retardés est de loin inférieure à celle observée dans le cas de la régulation par contraintes de capacité.

Si ce nouveau concept est accepté d'innombrables études portant sur l'amélioration de la gestion du trafic devraient s'en suivre. Je pense en premier lieu à une étude d'impact de différents systèmes de priorités de vols ou de groupes de vols particuliers.

INTRODUCTION

Ce rapport traite d'un changement fondamental des procédures de régulation des flux aériens. A ma connaissance, ce nouveau concept n'est pas présent dans les programmes officielles d'EUROCONTROL, de l'Union Européenne et d'autres organismes de contrôle aérien. Pour cette raison je tiens à rappeler la formule apparaissant sur la page de garde du fascicule:

Ce rapport ne reflète que les opinions de son auteur. Il ne représente nullement la politique officielle de l'Agence.

En outre, les résultats n'ont pas encore étaient validés par les opérationnels.

Enfin, quoique l'auteur eût bénéficié de nombreuses discussions avec des contrôleurs aériens et des contrôleurs de flux durant les 29 dernières années, il n'a jamais été, n'est pas et ne sera jamais, ni un contrôleur aérien ni un contrôleur de flux. Ainsi, dû à un manque de collaboration formelle avec des opérationnels (excepté l'aide périodique d'un contrôleur de flux de la CFMU, qui, d'ailleurs a été très efficace) l'étude n'a pu tenir compte que très partiellement des problèmes réels rencontrés journellement par les contrôleurs actifs.

Par conséquent, les idées exprimées sont personnelles et l'auteur regrette qu'elles n'aient jusqu'à maintenant attiré aucune attention de la part du monde opérationnel.

Le rapport est divisé en trois parties. La première partie revient sur l'arrière-fonds, explique les spécifications et l'installation du prototype pour finir sur une très courte analyse des résultats provisoires obtenus.

La deuxième partie est un rapport technique rédigé par E. Mercier, ingénieur de la société Cosytec, qui a réalisé la programmation du prototype.

La troisième partie est le manuel d'utilisateur.

CONCLUSION

Je répète que les résultats obtenus restent provisoires. Entre autres imperfections, ils ont été obtenus en donnant la même valeur numérique à des paramètres individuels comme la charge maximale par secteur et le délai maximal acceptable par avion. Pour s'approcher davantage de la réalité, ces valeurs doivent être individualisées. Cette adaptation ne peut être réalisée que par des opérationnels expérimentés.

En outre, les lacunes mentionnées dans le rapport devraient être comblées ultérieurement. Je pense en premier lieu à l'intégration au modèle de la régulation des aéroports. Toutes ces améliorations ne pourront se faire qu'en collaboration étroite avec des opérationnels actifs.

Néanmoins, malgré les imperfections citées, on peut dire dès maintenant qu'une régulation basée sur des contraintes de charge est plus efficace que celle basée sur des contraintes de capacité en termes de délais et de nombre d'avions retardés.

ETUDES ULTERIEURES

Si le nouveau concept proposé est accepté, je verrais des développements dans trois directions :

- Ajouter la régulation des aéroports à la régulation de l'espace aérien.
- Ajouter à la régulation par délais l'alternative de la régulation par reroutage.
- Adapter le modèle à un véritable outil de simulation pour tester l'impact de systèmes variés de priorités de vols, p.ex. priorités de flux entre certains paires d'aéroports

PART TWO

L C C R

REFERENCE MANUAL

1 INTRODUCTION

1.1 Acknowledgement

This document concerns the developer eager to be able to modify LCCR code. This document is a technical one and it will not describe LCCR operational facilities: it is aimed at giving the necessary information concerning the way the prototype was designed. The LCCR end-user who wishes to get practical and functional documentation is prompted to refer to the LCCR user's manual.

This document is divided into two main parts:

- the model: the first part deals with the exact description of the Load and Capacity Constraint Regulation (LCCR) prototype problem, so as no more ambiguity can remain concerning its aim and its rules;
- the code: the second part purpose is to provide the developer the necessary indications, so that she can enter the code of LCCR and correct or modify it.

1.2 The problematic: reminder

Let us give a short reminder of the context in which LCCR prototype was elaborated. Besides, we will refer to the LCCR prototype by naming it LCCR, so as to make things easier from now on.

The CFMU is given the responsibility to regulate the taking-off of air-planes (we talk more commonly of flight plans) from Europe, so that the different physical sectors and aerodromes should not be overloaded. This charge is done in real time by the air traffic controllers in Brussels. Here, to regulate an air-plane means to delay its departure time, if necessary. The constraint of load and capacity are not the only ones, and there are other constraints such as equity constraints (concerning flight plans with same departure and same destination), and priorities constraints (concerning flight plans of air-planes presenting different passengers capacity).

2 What LCCR proposes

So far, this regulation mission is given to the CASA system, which works with slots allocation. LCCR proposes to make up this regulation, regarding the main target, which is to regulate all the flight plans over all the sectors. This regulation is obviously a simulation.

2.1 What LCCR is not

LCCR is absolutely not a real-time application, since it was not designed for. The data concerning the flight plans are given as an entry to LCCR; nevertheless, the data resulting from the regulation made by LCCR is never given back to the system that provided the entry data. However, this does not imply that it would not be feasible with the technology used in LCCR...

2.2 LCCR purpose

LCCR purpose is to provide a decision help application for the CFMU controllers: thus, for a given day and all the flight plans scheduled during that day by the air companies, LCCR proposes a regulation simulation all over Europe, restrictively on the flight plans scheduled to be departed on that given day. This regulation is limited to the sectors, even if the aerodromes curfew constraint is taken into account; no regulation is performed on the aerodromes otherwise. To be a decision help application, on the one side it presents the demand as well on charts and on lists, on the other side, it presents the result of regulation. A particular effort was brought concerning the different tools of monitoring, so as to enable the end-user (an air traffic controller) to determine quickly what flight plan or what sector is mostly responsible for a given delay.

3 A short word concerning Constraint Programming (CP)

LCCR uses the Constraint Programming technology provided by Cosytec SA. This technology is based on a paradigm that enables the CP user to model its problem in terms of variables (discrete in our case), give to each of them an initial valid domain, express the constraints on them that represent the real constraints of the problem, and find a solution for all these variables, that is to say to give them a unique value. These three steps can be summed up as follows.

1. The real problem is thought in term of variables that have an initial valid domain representing the different values it can take a priori. These variables should be the unknowns of the problem.
2. The constraints of the problem must be thought as constraints on the variables, which means that the model must be designed so as to enable the CP user to model the constraints as well. Here, Cosytec SA supplies a pack of pre-defined global powerful constraints, on the one hand, that enable a more natural way of designing the different constraints, on the other hand, that deduce powerfully restrictions of the domain-variables.
3. Once these two steps achieved, the CP user must elaborate a strategy so as to find a feasible solution as fast as possible. Cosytec SA supplies a mechanism that enables the CP user to build dynamically a search tree, while always respecting the constraints.

4 The model

We now present the way the problem was modelled and the constraints expressed, as well as the strategy used to provide a solution. We present the design of the model. It is very important to understand this model if we want to be able to understand the way LCCR works to find a feasible solution.

4.1 The variables

Before all, let us notify the reader of the notation taken further: the indices e and r stand respectively for “estimated” and “regulated”. Off course, when a variable takes one of these two indices, it indicates that we refer to its estimated or regulated measure accordingly. The same kind of convention is taken for the exponents i and o , standing respectively for “in” and “out”.

The flight plans scheduling problem is easily modelled by variables. In this document, note that we use very often the expression flight plan: this is very often a shortcut to designate the air-plane itself, that is to say not only the conceptual list of elementary sectors crossed by a given air-plane, but also the physical air-plane itself. Indeed, each flight plan f is an element of the set F of all the flight plans scheduled to take off during the day the prototype is working on, and it is described by the following items.

4.1.1 Departure and arrival aerodromes of a flight plan

- Its departure and arrival aerodromes, noted respectively $da(f)$ and $aa(f)$.

4.1.2 Aircraft type

- The aircraft type of the air-plane, noted $AT(f)$.

4.1.3 Sectors entering and exiting times of a flight plan

- The different sectors it physically crosses (and the times it enters them, which are also variables, all linked to another as we will see): these sectors are noted $S(f) = \{s \in S, f \text{ crosses } s\}$, where S is the set of all the sectors on Europe (elementary and collapsed). The entry time in one sector s of $S(f)$ is noted $t^i(f, s)$ (i stands for “in”). So as to make things easier, we will consider that $t^i(f)$ is the departure time of the flight plan, and that $t^o(f)$ is its arrival time (o stands for “out”). For this flight plan f , the duration to cross physically sector s without taking into its co-ordination time $CT(s)$ (we explain later) is noted $d(f, s)$.

Note that it is supposed that all the flight plans are convex: this means that it is supposed that any given air-plane never crosses twice the same physical sector during the same flight plan. Otherwise, the problem overloading constraints may not set correctly and may be too restrictive compared with the actual problem.

4.1.4 The flight plan delay domain-variable

The only variable describing a flight plan is its real departure time. We consider two different departure times: the first departure time is the initial scheduled departure time as airline companies asked for it (and noted $t_e^i(f)$ where e stands for “estimated”), the second is the actual departure time of the flight plan once the regulation performed (noted $t_r^i(f)$). Thus, for each flight plan f , we consider what we call its delay, noted

$$d(f) = t_r^i(f) - t_e^i(f),$$

which correspond to the difference between the two departure times. Note that this delay can only be positive and that this delay is a domain-variable, which implies that it has a lower-bound value and an upper-bound value: we note them respectively $d_{\min}(f)$ and $d_{\max}(f)$. Now, we note:

$$d \in [d_{\min}(f), d_{\max}(f)], \quad d_{\min}(f) \leq d_{\max}(f).$$

This delay is a domain-variable, thus with a dynamic domain, and it is only when it is instantiated that this variable is bound. Thus, all along the solving, as long as the flight plan f is not placed, the delay domain-variable $d(f)$ is not instantiated, and its bounds $d_{\min}(f)$ and $d_{\max}(f)$ vary, depending on the various constraints posted on it. This is very important, mainly when we will talk about the constraints.

Since some relaxation is possible on the delay of a given flight plan f , we also give some formal symbols to its maximum delay $\max(f)$, that represents the upper bound of $d_{\max}(f)$; note that 0 is the lower-bound of $d_{\min}(f)$. At the beginning of the solving, $\max(f)$ is equal to $\max_0(f)$ (which corresponds to the demand), and with relaxation, $\max(f)$ increases but never exceeds $\max_1(f)$ (which corresponds to the maximum relaxation allowed). Thus, we can write the constraint on flight plan f :

$$d_{\min}(f) \geq 0, \quad d_{\max}(f) \leq \max(f), \quad \max_0(f) \leq \max(f) \leq \max_1(f).$$

4.1.5 Precision on the granularity and the time scale

Note that all the times are defined with the precision of the minute. Everywhere we refer to the term time (noted t) talking about an event, we do refer to the number of minute elapsed since the beginning of the day on which LCCR regulates.

Since LCCR only presents and regulates the flight plans estimated to take off during the day considered as the regulation day, there is no need to define any estimated take off date: this date is implicit and it is the regulation date. However, with the effect of the regulation and the delay involved, it is possible that LCCR should present some flight plans regulated to take off the day after.

4.1.6 Linear propagation of the delay

Moreover, we consider that, once it has taken off, a flight plan f does not increase the delay it has already taken at take off, which means that when you know the delay of that given flight plan f , you know all the entering times of the sectors it crosses. In terms of equation, we can write: $\forall f \in F, \forall s \in S(f),$

$$t_x^i(f, s) = t_e^i(f, s) + d(f).$$

Or, written in a different way:

$$t_x^o(f, s) = t_e^o(f, s) + d(f).$$

We define for each sector s the set of flight plans crossing it, noted $F(s) = \{f \in F, f \text{ crosses } s\}$.

For one flight plan f , there is only one unknown, which is its delay after regulation $d(f)$: all other variables $t_x^i(f, s)$ and $t_x^o(f, s)$ of that flight plan are related to the delay domain-variable by a linear equation, so that there is only one free variable per flight plan.

4.2 The constraints

Now that we have defined the variables of the problem, let us explain the different constraints we have posted on them.

4.2.1 The non overload constraint: ability constraint

This constraint is the main part of the constraints. It enables LCCR to express the fact that a sector must not be overloaded, either on load, or on capacity, or both. We remind that LCCR only regulates the flight plans departing the day of the regulation considered. For more convenience, we call this constraint the ability constraint in the future.

So as not to overload the reading of this document, we will only give the explanations concerning the load: the capacity constraint can be easily deduced from what has been said concerning the load constraint.

To explain this constraint, we have to go into more detail concerning the way the physical sectors are treated all over Europe.

4.2.1.1 The notion of sector

A sector is a physical volume of the European airspace. To each sector is assigned at least one air traffic controller. And yet, this does not involve that an air traffic controller is assigned to a single sector. Thus, a sector can be elementary on a time period, grouped with others in a collapsed sector on an other time period. It is necessary to introduce the elementary and the collapsed sectors so as to make things clear.

4.2.1.1.1 The elementary sector

The elementary sector is a sector that is monitored by an air traffic controller who does not monitor any other sector, during a time period of the day.

4.2.1.1.2 The collapsed sector

Whereas a collapsed is a gathering of sectors on which a controller is assigned during a time period of the day. Currently, we consider that a collapsed sector can only contain elementary sectors.

4.2.1.2 Characteristics of a sector: its ability

A sector noted s , elementary or collapsed, is given a load limit profile as well as a capacity limit profile: we talk about ability limit profile in general.

4.2.1.2.1 The load limit profile

The load limit profile $L(s)$ corresponds to the graph displaying number of air-planes that are allowed to be in at the same time. This load limit, noted $L(s, t)$ can vary during the day, t standing for the time. Indeed, the different load limits are given as an entry of the problem for each t , $0 \leq t < 24 * 60$. To help expressing the load relaxation, we note $L_0(s, t)$ the state of the profile at the beginning of the solving, that is to say the load limit profile demanded.

4.2.1.2.2 The capacity limit profile

Analogously, for the load limit profile, the capacity limit profile, noted $C(s)$, corresponds to the graph displaying the number of air-planes that are allowed to have entered s during the hour preceding t .

4.2.1.3 The constraint itself

We have just seen that each sector is given an ability limit profile. Besides, the definition of all the ability limits has been a problem that we encountered in LCCR, because of a lack of information and LCCR needs coherent information concerning the load and capacity limits to perform accurate regulation. But is exactly the constraint expressed ?

4.2.1.3.1 Load constraint

This constraint ensures that, for each sector s , the number of air-planes present in it at the same time t , can not overpass the load limit $L(s, t)$ of this sector, only for $0 \leq t < 24 * 60$. We have to give more precision about what we call “to be present”.

4.2.1.3.2 Capacity constraint

Obviously, the constraint concerning the capacity is built in the same spirit. We give the formal definition afterwards.

4.2.1.3.3 The co-ordination time of a sector: a major feature and impact on ability

To be more precise, we have to introduce the notion of co-ordination time $CT(s)$ of a given sector s . Each time an air-plane having the flight plan f enters sector s , we consider in fact that f is present in s $CT(s)$ minute before its real entrance. In LCCR, the co-ordination time does not vary during the regulation day.

This co-ordination time plays another role that we have to mention, so as to be precise: if a flight plan f was scheduled to enter physically a sector s after $t=0$, and that, with the co-ordination time $CT(s)$, it is scheduled to cross it before $t=0$, LCCR regulates flight plan f only on the part of its crossing time t such as $t \geq 0$. Nevertheless, this happens very rarely and does not affect regulation in general, since there is almost no regulation at midnight.

4.2.1.3.3.1 Its impact on load

It is easy to figure out that, the greater the co-ordination time is, the more constraining the load constraint is. This is why this co-ordination time can be considered as a major feature of the model when regulation by load.

4.2.1.3.3.2 Its impact on capacity

We note that the co-ordination time $CT(s)$ of sector s does affect the regulation only in the fact that it shifts the regulated capacity profile to the left: it does not make the constraint more constraining.

4.2.1.4 Its formal equation

We give the formal equations of the ability constraints, so that there is no ambiguity left.

4.2.1.4.1 Load

We note $NL(s, t)$ the number of air-planes present (taking into account the co-ordination time $CT(s)$ of sector s) at time t in sector s , and we note $t_x^o(f, s)$ the regulated exit time of flight plan f from sector s (o stands for "out"). Said in a more formal way, this load constraint ensures:

$$\forall s \in S, \forall t \in [0, 24 \cdot 60[, \\ NL(s, t) = \{ f \in F(s), t_x^i(f, s) - CT(s) \leq t < t_x^i(f, s) + d(f, s) \} \leq L(s, t).$$

4.2.1.4.2 Capacity

There is a major difference between the capacity and the load constraint usually used. The capacity takes into account all the flight plans that have been entering a given sector during the last hour, whereas the load constraint is a more instantaneous measure of sector loading. This notion of load was introduced to test whether such a constraint could improve the air traffic regulation, by minimising the global delay of flight plans. LCCR was partially built to compare a regulation by capacity versus a regulation by load.

So as to make things clear, we also give the capacity constraint formal equation:

$$\forall s \in S, \forall t \in [0, 24 \cdot 60],$$

$$NC(s, t) = \{ f \in F(s), t_r^i(f, s) - CT(s) \leq t < t_r^i(f, s) - CT(s) + 60 \} \leq C(s, t).$$

Here, $NC(s, t)$ represents the number of air-planes having entered the sector s during the full hour preceding t , taking into account the co-ordination time $CT(s)$ of sector s .

4.2.2 The flight plans equity constraint

This constraint concerns flight plans having the same departure and arrival aerodromes. If we consider two different flight plans f_1 and f_2 , assuming that f_1 is scheduled to take off before f_2 . In this case only, the equity constraint imposes that the initial order of the two flights should not be inverted after regulation, which means that:

$$\forall f_1 \in F, \forall f_2 \in F,$$

if

$$da(f_1) = da(f_2), aa(f_1) = aa(f_2) \text{ and } t_e^i(f_1) \leq t_e^i(f_2)$$

then

$$t_r^i(f_1) \leq t_r^i(f_2).$$

This constraint is called an equity constraint because it prevents flight plans that have a priori identical features, not to be randomly inverted because of the regulation. LCCR does not express this constraint in this way: an extra parameter is introduced so as to make the constraint a bit more flexible. This extra parameter is **equity_trigger**, expressed in minute, and we consider the equation:

$$t_r^i(f_1) \leq t_r^i(f_2) + \text{equity_trigger}.$$

The parameter **equity_trigger** settable through the solving parameters panel, allows the two flight plans to be inverted, but not too much and makes the constraint more operational. In other words, during the solving, f_1 is allowed to take off after f_2 only if it does not take off more than **equity_trigger** minute after f_2 .

4.2.3 The flight plans round-trip constraint

This constraint concerns the flight plans that uses the same air-plane to complete their corresponding journey, i.e. that performs a round-trip journey described by the two flight plans: it involves that the call sign of the second leg flight plan is the same as the one leg's except for the last digit which must be increased by one, that the aircraft type of the two flight plans is the same, that the departure aerodrome of each flight plan is the same as the arrival aerodrome of the other flight. Since these round-trip flights are not notified in the entry data of LCCR, in order to find these round-trip flight plans, LCCR uses an additional criteria. A flight plan f_2 is the return flight plan of a flight plan f_1 , if flight plan f_2 is scheduled to depart between **round_trip_mini** and **round_trip_maxi** minute after flight plan f_1 scheduled arrival. In equations, it makes: $\forall f_1 \in F, \forall f_2 \in F$,

if

$$da(f_1) = aa(f_2), aa(f_1) = da(f_2), AT(f_1) = AT(f_2) \text{ and } \text{round_trip_mini} \leq t_r^i(f_2) - t_r^o(f_1) \leq \text{round_trip_maxi}$$

then

f_1 (the first leg) and f_2 (the second leg) is a couple of round-trip flights.

In this case only, the round-trip constraint imposes that the delay of the return flight plan should be greater or equal to the delay of the one-way flight:

$$\forall f_1 \in F, \forall f_2 \in F, f_1 \text{ (the first leg) and } f_2 \text{ (the second leg) is a couple of round-trip flights,} \\ d(f_2) + \text{round_trip_trigger} \geq d(f_1).$$

As for the equity constraint, the parameter **round_trip_trigger** settable through the solving parameters panel, allows the constraint to be more operational and flexible: with it, the delay of the return flight plan f_2 is only impacted if the delay of the one-way flight plan f_1 is strictly greater than **round_trip_trigger**.

This constraint emphasises the fact that the same air-plane is used for the two flight plans, and that it needs to be re-prepared after the one-way journey.

4.2.4 The aerodromes curfew constraint

This constraint concerns the flight plans that take off or land on an aerodrome a subject to some curfew: during an aerodrome curfew $c(a)$, no flight can take off nor land on the aerodrome. This implies that the concerned flight plans can only take off and land respectively outside their departure and arrival aerodrome curfew. These flight plans will be delayed or limited in delay so as to respect this constraint.

An exception is accepted when the flight plan was formerly scheduled to take off or to land respectively during its departure or arrival aerodrome curfew. Moreover, the curfew on an aerodrome can be made of several periods. LCCR considers as well curfew on departure as curfew on arrival. More formally, we can write: $\forall f \in F$,

if $t_e^i(f) \notin c(da(f))$ then

$$t_r^i(f) \notin c(da(f)) \text{ and,}$$

if $t_e^o(f) \notin c(aa(f))$ then

$$t_r^o(f) \notin c(aa(f)).$$

4.2.5 The category constraint

This constraint handles the flight plans, whose aircraft types have disparate passenger capacities. This constraint forces flight plans to take into account the capacity of its passenger welcoming: thus, it introduces the notion of category.

4.2.5.1 Aircraft categories

LCCR introduces different categories of air-planes, sorted according to the number of passenger it is able to welcome. Currently, the first category gathers all aircraft types able to welcome more than 300 passengers, the second category gathers all aircraft types able to welcome between 100 and 300 passengers...

We note $CA(at)$ the category of the aircraft type at . For each category $ca \in CA$ where CA is the set of all categories, $\max(ca)$ (expressed in minute) is the maximum delay that all the flight plans of that category can accept. Thus:

$$\forall f \in F, \exists ca \in CA, CA(AT(f)) = ca, 0 \leq d(f) \leq \max(ca).$$

4.2.5.2 How it interferes with the priority constraint

Thanks to these categories, LCCR forces the flight plans to accept a maximum delay according to the category their aircraft belong to. Usually, the less the category is, the less the maximum delay is. But it is not always the case, and the end-user can set the categories as she wants.

Nevertheless, in all cases the category i is always considered to have a greater priority than category $i+1$. These categories enables LCCR to give different priorities to flight plans of different importance.

4.2.6 The exempted flight plan constraint

Also, LCCR enables the end-user to specify certain flight plans as exempted, which means that the delay of these flight plans must be null. If f is such an exempted flight, it means that $\max_0(d) = \max(f) = \max_1(f) = 0$ so that we always have $d(f) = 0$.

This constraint is necessary for certain kind of flight plans such as transatlantic ones on which no regulation can be made since the CFMU does not control their departure area. This constraint applies also to humanitarian flight plans, political flight plans, for instance.

4.3 The solver

This part is the most delicate part of this documentation: the reader will have to read it with much attention if she wants to be able to understand deeply how LCCR finds a feasible solution.

4.3.1 Before LCCR enumerates

4.3.1.1 Domain-variables definition

LCCR first defines all the domain-variables coming from the flight plans (departure times, delay and entry time in each sector, all linked to the delay) and from the sectors (load or/and capacity limit profile heights). LCCR gives to these domain-variables their largest domain taking into account their maximum relaxation. We explain why in the next paragraph.

4.3.1.2 Definition of the constraints

Once the domain-variables are defined, LCCR sets the different constraints, that is to say, it creates the constraints: the flight plans round-trip constraints, the flight plans equity-constraints, the aerodromes curfew constraints, the sectors load constraints (if asked for) and the capacity constraints (if asked for). At this step, since the domain-variables were given an initial range corresponding to their maximum relaxation, the problem is not already constrained as it should be: it is rather constrained with the full relaxation.

LCCR works this way, in order not to re-built each time the constraints, which is expensive in computing time: LCCR saves the state of the domain-variables at this level so as to be able to recover it very efficiently.

4.3.1.3 Posting the constraints

Now, LCCR is able to post the constraints asked for without relaxation. LCCR can enter this stage in two different states:

- it is the first time during the current solving that LCCR posts the constraints and no special method is used;
- it is not the first time that LCCR posts the constraints during the current solving, and a special method is called, since this step corresponds to the problem relaxation.

4.3.1.3.1 First time

It is supposed that no relaxation has been performed so far, when entering this stage. LCCR deals as well with constraints on the ability (load or/and capacity) profile heights as on the flight plans delays.

4.3.1.3.1.1 *The ability limit profile height variable*

LCCR posts on each sector the constraint on the height of its ability limit profile (load or/and capacity): this constraint ensures that the current demanded ability is not over-passed. However, it is possible that the constraint on this height is not feasible because the regulation problem is over-constrained: in this case, LCCR grants the necessary amount of relaxation (provided this amount does not exceed the maximum relaxation allowed when defining the domain-variables) so as the constraint posting does not fail, and thus, so that the satisfaction problem is respected. If, with all the relaxation allowed, one ability cannot be respected on a given sector, the corresponding constraint is ignored on that precise sector and LCCR solver fails to find a feasible solution.

4.3.1.3.1.2 *The flight plan delay variable*

Then, LCCR posts the constraints on the flight plans delays domain-variable, so as to specify that these variables are not allowed to exceed their current maximal value. However, it may happen that certain flight plans delay cannot be curbed enough: for these flight plans, LCCR grants just the necessary relaxation (provided it does not exceed the maximum relaxation given when defining the domain-variables) so that these flight plans can be placed.

In opposition to what is performed for the ability constraint posting, if a flight plan can not respect its demand maximum delay constraint, LCCR can always relax its delay within its maximum delay relaxation, so that this stage is always successful.

4.3.1.3.2 Not the first time: relaxation

In this case, it is not the first time LCCR posts the constraints: it is only the case when LCCR performs some relaxation. In this case, the two types of constraints are re-posted in the same order, but with the relevant domain-variables upper bounds re-adjusted.

4.3.1.4 Enumeration

All the constraints are posted, now the enumeration can start. We explain in the next paragraph the different strategies used in LCCR. However, each time the enumeration fails (partially or not), and that some relaxation is asked for, LCCR returns to the step before, that is to say to the constraints posting.

4.3.2 The main line strategy

LCCR tries to place all the given flight plans, respecting the different constraints. The strategy it adopts depends on the kind of regulation that the end-user selects: such a strategy that is set throughout the heuristic, will not be the same if the end-user launches a search for a load regulation as the one to regulate by capacity. As for the other constraints, the strategy can change a lot the quality of the results, and we will give some details so as to understand the importance of the priority parameters attached to the round-trip and the equity constraints. Nevertheless, we can describe a global strategy of LCCR.

4.3.2.1 A strategy to detect the flight plans that cannot be placed

This mechanism has been implemented to detect as soon as possible the flight plans that do not have any feasible delay value. This occurs when the constraints of the problem are not able to detect an inconsistency. To avoid that, and before choosing a group of flight plans, LCCR takes all the flight plans not yet placed one after another.

For each flight plan ϵ of these flight plans, LCCR tries to place it with one of the value of its domain. If the constraints fail each time, it means that the flight plan ϵ cannot be placed. Once all these flight plans have been tested, LCCR keeps only the flight plans that cannot be placed: we know that the problem will not have any solution if we do not grant to these flight plans an extra relaxation to their maximum delay. That is the reason why LCCR relaxes these flight plans with an extra step of relaxation (how this relaxation proceeds will be explained in the relaxation paragraph).

This process is continued as long as there is no more flight plan that cannot be placed. If this stage fails, relaxation on the abilities (load or/and capacity) of the sectors is launched and this stage is given up.

4.3.2.2 A strategy to choose the groups of flight plans

Indeed, LCCR does not try to place all the flight plans at the same time. It divides the set \mathcal{F} into smaller sets, and then tries to place these sets of flight plans. The way these groups of flight plans are chosen will be explained further, as well as the order in which they are instantiated within it. Once a group of flight plans has been totally instantiated (which implies with success), the flight plans of this group are never re-put into question, provided the solver is not re-launched. This means that the heuristic is highly important in this context.

Besides, the number of flight plans taken to build one group of flight plans is a parameter noted **group_percentage** that is settable through the solving parameters panel: LCCR gives the end-user the opportunity to indicate what percentage of flight plans are to be taken at each group definition. This percentage is the percentage related to the total number of flight plans to be regulated. The smaller this percentage **group_percentage** is, the slower the solver is to provide a solution. We will discuss more about this parameter when we have talked about the heuristic.

4.3.2.3 A strategy in the order the flight plans are instantiated within a group

As explained upper, there is another heuristic defined, which handles the flight plans of a group. Once a group of flight plans has been chosen by LCCR, these flight plans are going to be instantiated. This strategy defines

in what order the flight plans are placed, and it depends on the options selected in the solving parameters panel, as we will see.

4.3.2.4 A strategy for the delay of a given flight plan

At an even finer level, LCCR defines a strategy that chooses a feasible delay value for a given flight plan to be instantiated. This strategy will be discussed later on, and we will see that it depends on some other solving parameters dealing with the optimised results query.

4.3.3 Different strategies for different aims

4.3.3.1 The round-trip priority

First note that this option is effective only when the round-trip constraint is enabled. When this option is selected, LCCR will give priority to the round-trip flight plans. And yet, it does not mean that LCCR places first the round-trip flight plans. The strategy adopted is quite different when this option is enabled. Indeed, when a flight plan is bound to be placed, LCCR looks if this flight plan is part of a round-trip flight plan: and if it is the case, it does not only place this flight plan, but also the flight plan linked to it. And to improve its chance of success, LCCR tries to place first the one-way flight plan (even if it was not the one selected formerly to be instantiated), and only after it tries to place the return flight plan if the one-way flight plan could be placed. This option is most of the time to be selected because it prevents LCCR from placing the second leg flight plan of a round-trip flight plans couple with very little delay, whereas its corresponding first leg flight plan has not been placed yet, imposing then that its delay should be very limited because of the round-trip constraint (posted formerly on the couple of flight plans). If the round-trip priority is inactive and that LCCR first places the second leg flight plan without placing the first leg as well, relaxation on the first leg flight plan is inefficient since its maximum delay is already majored due to the placement of its second leg flight plan.

4.3.3.2 The equity priority

As for the round-trip priority, this equity priority is only efficient provided the equity constraint has been set active. When this option is made active, the way a solution is searched is similar to the strategy used when the round-trip priority is activated. Thus, when LCCR tries to place a flight plan, it looks whether this flight plan belongs to a group of flight plans linked by an equity constraint. If it is the case, LCCR not only tries to place the selected flight plan, but also all the equity flight plans estimated to depart before the flight plan selected. The order these flight plans are taken to be instantiated is given by their estimated departure time: locally, the first flight plan to take off is the first to be placed. When one of the equity constrained linked flight plan cannot be placed, LCCR considers that the former flight plan selected cannot be placed.

As for the previous priority, it is very wise always to activate this option. The reason is about the same as for the round-trip priority: if you do not activate this option, LCCR may place a flight plan with very little delay, while this flight plan belongs to a group of equity-constrained flight plans and that this flight plan is estimated to take off one of the last among the group. If the equity priority is inactive and that LCCR first places this flight plan, the maximum delay of the other flight plans of the group will be constrained to be somehow less delayed than the flight plan placed, and relaxation on them will be useless.

4.3.3.3 The round-trip and the equity priorities altogether

When both of the priorities are activated and if both their corresponding constraints are enabled, LCCR gives priority as well on the round-trip-constrained and the equity-constrained flight plans. In this case, when LCCR tries to place a flight plan, it first deals with the round-trip case. Afterwards, it deals with the equity case. Nevertheless, these two options selected altogether can provide a triggering behaviour to LCCR: if the round-trip-linked flight plan is itself part of an equity-constraint, the equity-constraint flight plans are also considered so as to be placed and so on. The consequence of this behaviour is that when LCCR tries to place a single flight plan, it can consequently place a lot of flight plans as well simultaneously, even if these flight plans are not part of the current flight plans group.

4.3.3.4 The category priority

This priority is used to decide between two flight plans from the current selected group that have the same priority of placement. In this precise case, so as to determine which one is to be placed the first, LCCR looks at the category their respective aircraft type belongs to, and first tries to place the one with the smallest category number. In fact, this criterion is very rarely used because, most of the time, the flight plans have different priorities of placement.

4.3.3.5 Regulation by load

We now explain the way the regulation by load is performed: thus, we are going to talk about the heuristic used in LCCR. All what will be discussed about load is also true concerning the capacity, but we will explain to the reader later how to make the interpolation.

4.3.3.5.1 Three evaluation tool: the load demand, the load critical and, the load forecasted profiles

These three profiles are used to build LCCR heuristic: we are going to describe each one of them, so as to explain part of the heuristic mechanism. Note that all these profiles are dynamically built: their layout is not constant within the same solving.

4.3.3.5.1.1 The load demand profile

We now describe one basic measure, which is the load demand profile of a given sector s , noted $LDP(s, t)$ (or $LDP(s)$ for the profile graph). This profile is defined for each sector, and it represents the current dynamic load demand profile; it is defined in the following way.

Considering a sector s , for each flight plan f that crosses s , the load demand profile is increased by one unit during the interval time Δt defined by $\Delta t = \{t, t_e^i(f, s) - CT(s) + d_{min}(f) \leq t < t_e^o(f, s) + d_{min}(f)\}$. This interval time represents the current occupation of flight plan f in sector s , as if f were placed with its current delay lower bound value $d_{min}(f)$.

When the contribution is defined on sector s for all the crossing flight plans $f \in F(s)$, we get this load demand profile. This profile's limit is the load regulated profile, i.e. when all the crossing flight plans $F(s)$ are placed on sector s , then the load demand profile is equal to the load regulated profile. Note that this profile is made of integer values and that it is dynamic.

Formally, $\forall s \in S, \forall t,$

$$\begin{aligned} \text{LDP}(s, t) = & \text{card}(\{f \in S(f), t_e^i(f, s) - \\ & \text{CT}(s) + d_{\min}(f) \leq t < t_e^i(f, s) + d(f, s) + d_{\min}(f)\}). \end{aligned}$$

4.3.3.5.1.2 The load critical profile

To understand how this regulation is done, we have to describe one other important measure, which is the load critical profile of a given sector s , noted $\text{LCP}(s, t)$ (or $\text{LCP}(s)$ for the profile graph).

This profile was designed in order to choose correctly the flight plans the most urgent to be placed; in other words, this profile helps LCCR to choose the next sectors to be relaxed if necessary. This profile is defined for each sector, and it represents the potential difficulty for a sector to accept all the flight plans scheduled to cross it. More precisely, it is defined in the following way.

Considering a sector s , for each flight plan f that crosses s , the load critical profile is increased by one unit during the interval time Δt defined by $\Delta t = \{t, t_e^i(f, s) - \text{CT}(s) + d_{\min}(f) \leq t < t_e^o(f, s) + d_{\max}(f)\}$. This interval time represents the maximum occupation of flight plan f in sector s . Note that this interval time Δt is never empty and that it is equal to the demand and to the regulated crossing interval time of flight plan f in sector s when flight plan f is placed.

When the contribution is defined on sector s for all the crossing flight plans $f \in F(s)$, we get this load critical profile. This profile is always above the load demand profile, and that is why we call it a critical profile. When all the crossing flight plans $F(s)$ are placed on sector s , then the load critical profile is equal to the load regulated profile. Note that this profile is made of integer values and that it is also dynamic.

Formally, $\forall s \in S, \forall t,$

$$\begin{aligned} \text{LCP}(s, t) = & \text{card}(\{f \in S(f), t_e^i(f, s) - \text{CT}(s) + d_{\min}(f) \leq t < \\ & t_e^i(f, s) + d(f, s) + d_{\max}(f)\}). \end{aligned}$$

4.3.3.5.1.3 The load forecasted profile

Another measure allows to refine dynamically the heuristic: this is the load forecasted profile of a given sector s , noted $\text{LFP}(s, t)$ (or $\text{LFP}(s)$ for the profile graph).

This profile was also designed in order to choose correctly the flight plans the most urgent to be placed. This profile is defined for each sector, and it represents the potential difficulty for a sector to accept all the flights scheduled to cross it: this measure is very close to the load critical profile, but it is less critical however. It is defined in the following way.

Considering a sector s , for each flight plan f which crosses s , the load forecasted profile is increased by $(d(f, s) + \text{CT}(s)) / (d_{\max}(f) - d_{\min}(f) + d(f, s) + \text{CT}(s))$ unit during the interval time Δt defined by $\Delta t = \{t, t_e^i(f, s) - \text{CT}(s) + d_{\min}(f) \leq t < t_e^o(f, s) + d_{\max}(f)\}$. This interval time represents the maximum occupation of flight plan f in sector s (as for the critical profile). Note that this interval time Δt is never empty and that it is also equal to the demand and regulated crossing interval time of flight plan f in sector s when flight plan f is placed.

When the contribution is defined on sector s for all the crossing flight plans $f \in F(s)$, we get this load forecasted profile. This profile is a normalisation of

the current load critical profile, representing an equi-probabilistic load profile, and that is why we call it a forecasted profile. When all the crossing flight plans $F(s)$ are placed on sector s , then the load forecasted profile is equal to the load regulated profile. Note that this profile is made of real floating values and that it is once again dynamic.

Formally, $\forall s \in S, \forall t,$

$$LFP(s, t) = \sum_{f \in F(s)} \frac{d(f, s) + CT(s)}{d_{\max}(f) - d_{\min}(f) + d(f, s) + CT(s)} \delta_L(s, t)$$

where:

$$\delta_L(s, t) = 1 \text{ if } t_e^i(f, s) - CT(s) + d_{\min}(f) \leq t < t_e^i(f, s) + d(f, s) + d_{\max}(f),$$

$$\delta_L(s, t) = 0 \text{ otherwise.}$$

4.3.3.5.2 Link with the load profiles : the load over volumes

All these profiles enable LCCR to consider some other functions helpful for the heuristic, mostly during the relaxation. Note that all these functions take into account the co-ordination time $CT(s)$ of each sector s , which magnifies a lot the load constraint.

4.3.3.5.2.1 The load demand over volume

For a given sector, the load demand profile is considered so as to be compared with the load limit profile, which is the graph representing at any time t the load limit accepted by the corresponding sector, and that was already noted $L(s, t)$ for a given sector s (or $L(s)$ for the profile graph). By comparing these load demand over volumes, LCCR sorts the sectors. The dynamic upper surface (which is called a volume) between the load limit profile and the load demand profile is called the load demand over volume, and is noted $LDOV(s)$ for a given sector s .

Formally, $\forall s \in S,$

$$LDOV(s) = \sum_{t=0}^{t=24*60-1} \max(LDP(s, t) - L(s, t), 0).$$

We also define the load demand volume $LDV(s)$, which is the total amount of minute during which the sector s is crossed (including the co-ordination time $CT(s)$):

$$LDV(s) = \sum_{t=0}^{t=24*60-1} LDP(s, t).$$

Note that this measure is constant all solving long: what LCCR performs is to shift this load volume so as not to overpass the load limit profile.

4.3.3.5.2.2 The load critical over volume

For a given sector, the load critical profile is also evaluated so as to be compared to the load limit profile. When the load critical profile does never exceeds the load limit profile, LCCR is ensured that there will no problem on the given sector, from a load constraint point of view at least. Nevertheless, when this load critical profile exceeds the load limit profile, it is possible that the corresponding sector might be overloaded. Of course, this does not mean that it will be overloaded and that regulation has to be performed on it, but by comparing these load critical over volumes, LCCR can sort the sectors.

The dynamic upper surface (which is called a volume) between the load limit profile and the load critical profile is called the load critical over volume, and is noted $LCOV(s)$ for a given sector s .

Formally, $\forall s \in S$,

$$LCOV(s) = \sum_{t=0}^{t=24*60-1} \max(LCP(s, t) - L(s, t), 0).$$

We also define the load critical volume $LCV(s)$, which is the total amount of minute during which the sector s would be crossed (including the coordination time $CT(s)$) if each flight plan $f \in F(s)$ of all the flight plans crossing it crossed it during a period increased by its delay domain-variable $d(f)$ range $d_{\max}(f) - d_{\min}(f)$:

$$LCV(s) = \sum_{t=0}^{t=24*60-1} LCP(s, t).$$

Here, this measure is not constant but tends to be equal to the load demand volume $LDV(s)$: the more flight plans are placed, the closer the load critical volume to the load demand volume is. This value does not represent anything concrete, that is why, afterwards, we will consider a value deduced from it.

4.3.3.5.2.3 The load forecasted over volume

For a given sector, the load forecasted profile is evaluated so as to be compared to the load limit profile. By comparing these load forecasted over volumes, LCCR can sort the sectors.

The dynamic upper surface (which is called a volume) between the load limit profile and the load forecasted profile is called the load forecasted over volume, and is noted $LFOV(s)$ for a given sector s .

Formally, $\forall s \in S$,

$$LFOV(s) = \sum_{t=0}^{t=24*60-1} \max(LFP(s, t) - L(s, t), 0).$$

We do not have to introduce the load forecasted volume $LFV(s)$, since it is equal to the constant load demand volume $LDV(s)$:

$$LFV(s) = LDV(s).$$

4.3.3.5.3 The heuristic to choose a group of flight plans

Now, we return to the heuristic used to select a group of flight plans. When LCCR regulates by load, it uses fully these load profiles.

LCCR computes the load profiles on all the sectors (elementary and collapsed). For each one of these profiles, it defines the load over volumes, which represent the surfaces of the load profiles above the load limit profile, as we just introduced it. LCCR does not try to place all the flight plans of a sector, but instead, it tries to place first the most critical flight plans. To do so, LCCR considers a load priority function for each flight plan f , which will be referred to by the notation $p_L(f)$.

4.3.3.5.3.1 The flight plan load priority function

We now give the way the flight plan load priority function is built. Given a flight plan f , we consider recursively all the sectors (elementary and collapsed) that it might physically cross, $S(f)$. And, for each sector $s \in S(f)$ it crosses, LCCR computes its contribution to the eventual overloading volume during the interval time it would cross s if its delay $d(f)$ were equal to its current delay lower bound value $d_{\min}(f)$. This contribution is added to $p_L(f)$, which was previously reset to 0.

More formally,

$\forall f \in F,$

$$p_L(f) = \sum_{s \in S(f)} \sum_{t=t_e^i(f,s)-CT(s)+d(f,s)+d_{min}(f)-1}^{t=t_e^i(f,s)-CT(s)+d(f,s)+d_{min}(f)-1} \max(LDP(s,t) - L(s,t), 0).$$

4.3.3.5.3.2 How the flight plans are ordered

Thus, we get for each flight plan a sum of all the crossed sectors contribution. LCCR sorts the flight plans not yet placed by decreasing priority. It then normalises the load priority by giving the value 100 to the flight plan with the highest load priority noted $P_L = \max\{p_L(f), f \in F\}$, and for each flight plan f , the previous priority $p_L(f)$ is replaced by $p_L(f) / P_L$.

Now the flight plans are sorted and LCCR chooses the next group of flight plans to be placed. The size of this group depends on a solving parameter, which is the flight plan group percentage noted **group_percentage** (expressed between 0 and 1). This parameter represents the percentage of the total flight plans to be chosen each time for one group. Only **card(F) * group_percentage** flight plans will be chosen, except if all the flight plans not yet placed have a null priority: in this case, all the flight plans left are selected. Note that this special case appears when all the flight plans not yet placed can be placed at their current delay lower bound, since their priority is null.

4.3.3.5.4 The heuristic to choose a flight inside a group

This heuristic is half dynamic, depending on a quality factor referred as **search_quality** (ranging from 0 to 999) set through the solving parameters panel. Indeed, each time **1000 - search_quality** flight plans are placed, LCCR re-computes the order in which it chooses the flight plans not yet placed inside the same current group. The order is given by the decreasing load priority for each flight plan, computed in the previous stage. Thus, the higher this search quality factor is, the finer and the more dynamic the heuristic is.

4.3.3.5.5 The heuristic to choose a delay for a given flight plan

4.3.3.5.5.1 No optimisation asked for

This heuristic is very basic when the optimisation is not set on the solving parameters panel. When LCCR tries to place a flight plan f , it simply tries to place it with a delay equal to the lower bound value $d_{min}(f)$ of its current delay domain-variable $d(f)$. This strategy globally tends to minimise the total sum of the flight plans delays.

4.3.3.5.5.2 Optimisation parameters

However, the strategy is more complex when some optimisation parameters are active. Three optimisation options are available in LCCR: either the end-user chooses to minimise the number of flight plans delayed, or she wants to minimise the total delay sum of all the flight plans (said in another way, the average delay per flight plan), or she decides to minimise the average delay per delayed flight plan (average delay per delayed movement).

4.3.3.5.5.2.1 Number of flight plans delayed optimisation

Before setting a given flight plan f to a feasible delay value, LCCR tries a range of feasible delay value. LCCR contemplates each of these feasible

delay values, and will try to instantiate the delay domain-variable $d(f)$ to the value that minimises the number of flight plans delayed.

The way to know what is the best value is to store the state of all the domain-variables, instantiate the corresponding flight plan delay domain-variable $d(f)$ to one of its domain value, look at the constraints propagation deduction, and keep the value that minimises our criteria.

4.3.3.5.2.2 Average delay per flight plan optimisation

Before setting a given flight plan f to a feasible delay value, LCCR tries a range of feasible delay value. LCCR contemplates each of these feasible delay values, and will try to instantiate the delay domain-variable $d(f)$ to the value that minimises the total sum of the flight plans delays.

The way to know what is the best value is to store the state of all the domain-variables, instantiate the corresponding flight plan delay domain-variable $d(f)$ to one of its domain value, look at the constraints propagation deduction, and keep the value that minimises our criteria.

4.3.3.5.2.3 Average delay per delayed flight plan optimisation

The technique is about the same. Before setting a given flight plan f to a feasible delay value, LCCR tries a range of feasible delay values. LCCR contemplates each of these feasible delay values, and will try to instantiate the delay domain-variable $d(f)$ to the value that minimises the average delay per delayed flight plan.

4.3.3.6 Regulation by capacity

There is not much to say concerning the regulation by capacity: everything that has been said concerning the load regulation can be interpreted as well for the capacity, just by considering a crossing time duration of 60 minutes for each sector crossed by a flight plan.

4.3.3.6.1 Link with the load

In other words, LCCR works with capacity in the same way as for the load; all the equations remain correct if you replace $d(f, s) + CT(s)$ by the value 60.

4.3.3.6.2 The formal equations

So as the reader makes no confusion, we give the definitions related to the capacity regulation:

$\forall s \in S, \forall t,$

$$CDP(s, t) = \text{card}(f \in S(f), t_e^i(f, s) - CT(s) + d_{\min}(f) \leq t < t_e^i(f, s) - CT(s) + 60 + d_{\min}(f)),$$

$$CCP(s, t) = \text{card}(f \in S(f), t_e^i(f, s) - CT(s) + d_{\min}(f) \leq t < t_e^i(f, s) - CT(s) + 60 + d_{\max}(f)),$$

$$CFP(s, t) = \sum_{f \in S(f)} \frac{60}{d_{\max}(f) - d_{\min}(f) + 60} \delta_c(s, t)$$

where:

$$\delta_c(s, t) = 1 \quad \text{if} \quad t_e^i(f, s) - CT(s) + d_{\min}(f) \leq t < t_e^i(f, s) - CT(s) + 60 + d_{\max}(f),$$

$\delta_c(s, t) = 0$ otherwise

$$CDOV(s) = \sum_{t=0}^{t=24*60-1} \max(CDP(s, t) - C(s, t), 0)$$

$$CCOV(s) = \sum_{t=0}^{t=24*60-1} \max(CCP(s, t) - C(s, t), 0)$$

$$CFOV(s) = \sum_{t=0}^{t=24*60-1} \max(CFP(s, t) - C(s, t), 0).$$

$\forall f \in F,$

$$p_c(f) = \sum_{s \in S(f)} \sum_{t=t_o^i(f, s) - CT(s) + d_{min}(f)}^{t=t_o^i(f, s) - CT(s) + 60 + d_{min}(f) - 1} \max(CDP(s, t) - C(s, t), 0).$$

4.3.3.6.3 Same mechanism

The operations described concerning the load regulation are the same for the capacity regulation: the different steps do not change, only the flight plan priority and the profiles functions change.

4.3.3.7 Regulation by load and capacity

Regulation by load and by capacity is possible as well on LCCR. Nevertheless, because of memory use restrictions, it is not advisable to launch a solving on an important set of data exceeding 20 000 flight plans. LCCR considers as well the load priority of a given flight plan f , as its capacity priority: the priority of the flight plan f is $p(f) = p_L(f) + p_c(f)$. With this extra datum, LCCR follows the same steps as described before. Nothing more special is to be noted concerning this double regulation, except for the relaxation, and we will discuss this issue later.

4.3.4 Relaxation

This mechanism is essential in LCCR, since most of the data are over-constrained. LCCR provides the opportunity to soften somehow different constraints of the problem. Without relaxation, no solution could be provided, simply because there is no solution. That is the reason why we stress the importance of the corresponding solving parameters, which modify a lot the physiognomy of a solution. Much care is to be brought by the end-user on the definition of the different relaxation parameters.

4.3.4.1 Global mechanism

There is a global mechanism concerning the relaxation on LCCR: LCCR always relaxes first on the maximum delay of the flight plans, and if there is still no solution, it relaxes the abilities of the sectors (load or/and capacity). We first detail the mechanism concerning the flight plans delay maximum relaxation, and then the relaxation on the sectors abilities.

4.3.4.2 The flight plans delay relaxation

This is the first kind of relaxation performed by LCCR. This relaxation occurs when a group of flight plans cannot be placed entirely, that is to say when LCCR does not find any proper delay value for at least one flight plan. This

relaxation is active only if the corresponding solving parameter is enabled (by default, it is), and if the other related parameters (`delay_relaxation_step_percentage` and `delay_relaxation_maximum_percentage`) values are coherent.

In this case, LCCR gives some extra relaxation by one step of relaxation to all the flight plans not yet placed. This step is a customisable parameter of the solving parameters panel, and we note it `delay_relaxation_step_percentage`. Let us explain how this relaxation is performed on a flight plan f not yet placed.

- If flight plan f has already used the maximum allowed relaxation, that is to say if the delay relaxation percentage of flight plan f , noted `relaxation(f)`, is greater or equal to `delay_relaxation_maximum_percentage`, no additional relaxation is performed on f .
- Otherwise, flight plan f is increased its delay relaxation percentage by increasing `relaxation(f)` by `delay_relaxation_step_percentage` %, without exceeding `delay_relaxation_maximum_percentage` %.

This delay relaxation percentage `relaxation(f)` is used to define a new flight plan delay upper bound by replacing its former value by the corresponding percentage of the initial upper bound delay. More formally, if flight plan f is performed one relaxation step on its delay domain-variable, we can write that `relaxation(f)` becomes `min(relaxation(f)+delay_relaxation_step_percentage, delay_relaxation_maximum_percentage)` and `max(d)` becomes `max0(d)*(1+relaxation(f))`, all the percentages being expressed between 0 and 1. This mechanism ensures that relaxation never overpasses the global `delay_relaxation_maximum_percentage` value for all the flight plans. Moreover, we see that relaxation is inefficient concerning the exempted flight plans since, for them, `max0(d) = 0`.

Note that, with relaxation, the other constraints (round-trip and equity) are still handled by the solver.

If no more delay relaxation is possible, i.e. when all the flight plans not yet placed are already fully relaxed or when delay relaxation is not active, LCCR performs relaxation on the sectors abilities.

4.3.4.3 The sectors load relaxation

We suppose that the end-user regulates by load and that she has set the flight maximum delay relaxation mechanism on. This is the second type of relaxation performed by LCCR. The mechanism described bellow is active only if the end-user has made the corresponding solving parameters active and if she has properly defined the other related parameters (`load_relaxation_percentage` and `load_relaxation_maximum_percentage`). This relaxation is part of the sectors abilities relaxation.

When no more flight plan delay relaxation can be performed, LCCR relaxes the load maximum profile $L(s)$ of some sectors (collapsed and elementary) so as to provide a solution to the problem. All the problem consists in finding the relevant sectors to be relaxed, that is to say the sectors that prevent currently the solver from finding a solution. To find them, LCCR uses all the previously described evaluation tools.

4.3.4.3.1 The sector load priority function

This function is very decisive concerning the quality of the solution when the problem is over constrained. For a given sector s , we note $p_L(s)$ its load priority concerning the relaxation: this load priority should emphasise the urgency to relax the corresponding sector in case of load-relaxation. The more the dynamic load demand profile exceeds the load maximum profile, the more probable is the sector to be relaxed. This is the idea used when load relaxation is performed by LCCR. In an empirical manner, we define the load priority $p_L(s)$ of a sector s as a linear combination of its load over volumes, i.e. of its load demand, critical (normalised as we will see) and forecasted volumes. More formally, $\forall s \in S$,

$$p_L(s) = \alpha * LDOV(s) + \beta * LFOV(s) + \gamma * LCOV^*(s)$$

with $LCOV^*(s) = LCOV(s) * LDV(s) / LCV(s)$ with $\gamma \leq \beta \leq \alpha$.

And so as to give precedence to the load demand over volume which is the most reliable function, α is greater than β and γ . Moreover, as the load forecasted volume seems to be empirically better than the load critical profile, β is greater than γ . The normalised load critical over volume $LCOV^*$ is used instead of the load critical over volume $LCOV$ so as to curb its impact and so as to get an homogeneous priority expressed in minute. Note that when $LCOV(s)$ is null, all the other over volumes are null as well and that consequently $p_L(s)$ is also null.

These factors are delicate to tune, and with $\alpha=3$, $\beta=2$ and $\gamma=1$, LCCR seems to be set correctly.

4.3.4.3.2 Selecting the relevant sectors to relax

Once the load priority functions computed for each sector, LCCR sorts the sectors in a decreasing priority order. It considers the sector s with the greatest $p_L(s)$ noted $P_L(s)$ and all the sectors with a priority greater or equal than $P_L(s)$ decreased by `ability_relaxation_percentage` % (`ability_relaxation_percentage=30` seems to be a well tuned value): only these selected sectors will be load-relaxed by an additional step of `load_relaxation_step_percentage` %. More precisely, the way each sector s of these sectors is relaxed follows about the same rule as for the flight plans delay relaxation.

- If the sector s has already used the maximum allowed relaxation, that is to say if the load relaxation percentage of sector s , noted $relaxation_L(s)$, is greater or equal to `load_relaxation_maximum_percentage`, no additional relaxation is performed on s .
- Otherwise, sector s is increased its load relaxation percentage by increasing $relaxation_L(s)$ by `load_relaxation_step_percentage` % without exceeding `load_relaxation_maximum_percentage` %.

This load relaxation percentage $relaxation_L(s)$ is used to define a new sector limit profile by raising its former value by the corresponding percentage of the initial limit profile. More formally, if sector s is performed one more relaxation step, its $relaxation_L(s)$ becomes $\min(relaxation_L(s) + load_relaxation_step_percentage, load_relaxation_maximum_percentage)$ and its limit profile $L(s)$ is raised to $L_0(s) * (1 + relaxation_L(s))$ unit ($L_0(s)$ being the demand limit profile graph), all the percentages being expressed between 0 and 1.

This mechanism ensures that relaxation never overpasses the global `load_relaxation_maximum_percentage` value for all the sectors.

It is important to note that the relaxation is spread all over the day on which LCCR regulates: indeed, the load limit profile is increased by the same amount of unit during all day, that is to say with $t \in [0, 24 \cdot 60[$. As far, an independent relaxation on each open period is not implemented, but it can be contemplated.

4.3.4.3.3 No more possible load relaxation

As for the flight plans delay relaxation, when all the sectors have been fully relaxed, and yet LCCR cannot find a solution to the problem, the solving is stopped and the end-user is notified that there is no feasible solution.

4.3.4.4 The sectors capacity relaxation

The mechanism is the same as for the load relaxation: the capacity relaxation has its own `capacity_relaxation_step_percentage` %, `capacity_relaxation_maximum_percentage` %, solving parameters accessible from the solving parameters panel as well. The capacity priority function $p_c(s)$ is defined in an analogue way, and the capacity relaxation percentage $relaxation_c(s)$ is also defined for each sector s .

4.3.4.5 The sectors load and capacity relaxation

In this case, the mechanism is the same as before, including the solving stop condition. When both load and capacity regulations are asked for and that LCCR comes to the ability relaxation, it considers a priority function $p(s)$ including load and capacity. This priority functions emphasises the need for a given sector s to be relaxed on load and on capacity: very simply, it is the sum of the load priority function $p_L(s)$ and of the capacity priority function $p_c(s)$, that is to say: $\forall s \in S$,

$$p(s) = p_L(s) + p_c(s).$$

This priority function is used to sort the sectors in a decreasing order, so that LCCR only relaxes the most urgent sectors. Note that relaxation on load cannot be separated from relaxation on capacity, and inversely: each time a load-relaxation step is performed on a sector, a capacity-relaxation is performed as well.

5 The code

Now that the model has been presented, we can present the way it was coded. LCCR was fully coded in C++ for more convenience.

5.1 A word concerning the UNIX to NT migration

To explain why LCCR now runs on a PC, we have to explain its genesis. LCCR was formerly being developed under HP UNIX V10.2 server *wotan*, whose capacities were too weak; however, we did not want to re-write the whole graphical stuff. That is the reason why we decided to migrate the application to Microsoft WINDOWS NT V4.0. As a consequence, the prototype can run as well on HP UNIX as on WINDOWS NT, even if no test has been done so far on HP UNIX.

5.2 The environment

We here give some details concerning the environment in which LCCR prototype was coded.

5.2.1 Different software libraries used

LCCR uses four main software libraries described below:

- Chip-C++ V5.2.1 library, which delivers all the CP kernel enabling to express variables, constraints, so as to be able to enumerate a solution. This library is the property of Cosytec SA..
- Loox++ and Loox Extension Pack in C++ V3.3 libraries (LxPack++), which enable to design the Graphic User Interface (GUI), include editable lists and Gantt diagrams. These libraries are the property of Loox Informatique SA..
- X Development Kit V6.1 (XDK) libraries, which enable to emulate a PC into a X client-server platform. These libraries were useful and enabled us not to re-code the whole GUI when we came from UNIX to WINDOWS NT. These libraries are the property of Hummingbird company.
- At last, X-Designer software that enabled us to design the frames architecture graphically. This product generates automatically C++ code, which was used in LCCR to handle the graphic, designed via LxPack++. The product belongs to Imperial Software Technology (IST) company.

5.2.2 The exact content

We give hereby the exact content of all these libraries, so as re-compilation and re-linkage of LCCR should be easy with these modules. The reference are given on PC KAYAK XAs *mei*.

<i>product</i>	<i>static library path</i>	<i>static libraries</i>	<i>dynamic libraries</i>	<i>header files path</i>
Chip-C++	%CHIPCDIR%\Lib	chipccrmt.lib		%CHIPCDIR%\Include
LxPack++	C:\Loox V3.3\Lib	Loox.lib, Loox++.lib, LxChart++.lib, LxPack.lib	Loox++.dll, Loox.dll	C:\Loox V3.3\Include
XDK	C:\Program Files\Exceed V6.1\xdk\lib	xlib.lib, xmStatXt.lib, xmstatic.lib, xlibcon.lib	Xlib.dll...	C:\Program Files\Exceed V6.1\xdk\include

5.2.3 To recompile: the mode of compilation and of linkage

It is essential to know the way the application was compiled and linked so as to be able to rebuilt it after some code modification.

The application was developed under Microsoft Developer Studio V6.0 Rapid Application Development (RAD). This RAD proposes a multithreaded dynamic linkage, which was used. This mode must be re-used to re-compile LCCR. No other major feature is to be specific for its re-compilation and re-linkage.

5.2.4 At run-time

Some of these libraries are still necessary in order to execute LCCR. This is the case of the LxPack++ and of the XDK dynamical linked libraries, for instance.

5.3 The application architecture

We will not describe precisely how LCCR was coded, but we give the main lines adopted, that is to say the LCCR architecture.

5.3.1 General architecture

We can describe LCCR objects in a global way: LCCR uses aerodrome, sector, aircraft type, category, flight classes. LCCR also introduce the notion of ability class that describes aerodrome and sector capacity or/and load limit profile and open periods. LCCR also manipulates collections of instances of those classes.

The code is commented as much as possible (even if a code is never commented enough) so as to enable the developer to understand the purpose of classes, functions and methods. We do hope the names given to these objects are evocative enough.

5.3.2 The COFEE data extraction

The extraction of COFEE environment data is performed by LCCR, so as to provide the necessary LCCR files: these LCCR files constitute the entry data of the application. The COFEE data are not directly taken as entry data, but are beforehand read and put into a LCCR format to provide a steady entry point for LCCR.

The reason for the creation of intermediate files is that the COFEE files architecture does not fit in the way LCCR treats the data, and without the creation of the LCCR intermediate files, the reading of the entry data would be too long each time.

5.3.2.1 Necessity of an intervention by hand

However, LCCR needs the COFEE extraction already submitted and the COFEE data locally in the proper directory gathered. LCCR does not call COFEE and tell it to submit the necessary queries, retrieve the data from the queries result: it is the responsibility of the end-user to do that job, and to put the information retrieved by COFEE in a proper directory.

5.3.2.2 The flight plans file

From COFEE is only taken the environment for the day on which the end-user wishes to make some regulation simulation. When LCCR prototype was started, the information concerning the flight plans was not correctly available through COFEE. That is the reason why we use an heterogeneous source of data concerning the flight plans description: the flight plans entry data come from the *all-flights* file, which describes all the flight plans for a given day. This file should be present as well, so that LCCR data extraction should be possible.

5.3.2.3 The permanent LCCR files

In addition, LCCR, uses some permanent LCCR files, which should not be touched by the end-user. These files give the information concerning the different categories, the default capacities of sectors. Without them, LCCR will not be able to read any LCCR data.

5.3.2.4 The impact on the object architecture

LCCR code includes some data extraction classes, which are specific to that task and derived from the base classes introduced upper.

5.3.3 The LCCR data reading

This operation enables to load the entry LCCR data into memory. The objects created are instances of constraints classes derived from the base

classes already introduced. Notably, these classes use the CHIP domain-variables and constraints.

5.3.4 The LCCR solver

The solver uses the previous objects and defines correctly the domain-variables and the constraints posted on them. Its aim is to built a search tree, so as to find a solution.

5.3.5 The LCCR GUI

The GUI interface is made mainly of editable lists and chart diagrams. LCCR uses instances of classes representing each of these objects to represent them, and to interact with them.

6 Index

We sum up some notations used throughout this document, so as to make its reading easier.

$aa(f)$	arrival aerodrome of flight plan f
$AT(f)$	aircraft type of flight plan f
$CA(at)$	category of the aircraft type at
$max(ca)$	maximum delay of category ca
$CT(s)$	co-ordination time of sector s
$da(f)$	departure aerodrome of flight plan f
$c(a)$	curfew of aerodrome a (set of times)
$C(s)$	capacity limit profile graph of sector s
$C_0(s)$	capacity limit initial profile graph of sector s (demand)
$C(s, t)$	capacity limit profile of sector s at time t
$C_0(s, t)$	capacity limit initial profile of sector s at time t (demand)
$CCOV(s)$	capacity critical over volume of sector s
$CCP(s, t)$	capacity critical profile of sector s at time t
$CDOV(s)$	capacity demand over volume of sector s
$CDP(s, t)$	capacity demand profile of sector s at time t
$CFOV(s)$	capacity forecasted over volume of sector s
$CFP(s, t)$	capacity forecasted profile of sector s at time t
$d(f)$	delay of flight plan f (domain-variable)
$F(s)$	set of flight plans crossing sector s (elementary or collapsed)
$d_{max}(f)$	flight plan f delay $d(f)$ upper-bound
$d_{min}(f)$	flight plan f delay $d(f)$ lower-bound
$d(f, s)$	physical crossing duration of flight plan f in sector s (not taking into account the sector co-ordination time $CT(s)$)
$L(s)$	load limit profile graph of sector s
$L_0(s)$	load limit initial profile graph of sector s (demand)
$L(s, t)$	load limit profile of sector s at time t
$L_0(s, t)$	load limit initial profile of sector s at time t (demand)

$LCOV(s)$	load critical over volume of sector s
$LCP(s, t)$	load critical profile of sector s at time t
$LDOV(s)$	load demand over volume of sector s
$LDP(s, t)$	load demand profile of sector s at time t
$LFOV(s)$	load forecasted over volume of sector s
$LFP(s, t)$	load forecasted profile of sector s at time t
$\max(f)$	current maximum value of $d_{\max}(f)$
$\max_0(f)$	initial maximum value of $\max(f)$ (without any relaxation)
$\max_1(f)$	final maximum value of $\max(f)$ (with relaxation)
$NC(s, t)$	number of flight plans having entered sector s during the hour preceding time t (taking into account the sector co-ordination time $CT(s)$)
$NL(s, t)$	number of flight plans present in sector s at time t (taking into account the sector co-ordination time $CT(s)$)
$p(f)$	priority function of flight plan f
$p(s)$	relaxation priority function of sector s
$p_c(f)$	capacity priority function of flight plan f
$p_c(s)$	capacity relaxation priority function of sector s
$p_L(f)$	load priority function of flight plan f
$p_L(s)$	load relaxation priority function of sector s
$relaxation(f)$	delay relaxation percentage of flight plan f
$relaxation_c(s)$	capacity relaxation percentage of sector s
$relaxation_L(s)$	load relaxation percentage of sector s
$S(f)$	set of sectors (elementary and collapsed) crossed by flight plan f
$t^i(f)$	departure time of flight plan f
$t^i_e(f)$	estimated departure time of flight plan f
$t^i_r(f)$	regulated departure time of flight plan f
$t^i(f, s)$	entry time of flight plan f in sector s
$t^i_e(f, s)$	estimated entry time of flight plan f in sector s
$t^i_r(f, s)$	regulated entry time of flight plan f in sector s
$t^o(f)$	arrival time of flight plan f
$t^o_e(f)$	estimated arrival time of flight plan f
$t^o_r(f)$	regulated arrival time of flight plan f
$t^o(f, s)$	exit time of flight plan f from sector s
$t^o_e(f, s)$	estimated exit time of flight plan f from sector s
$t^o_r(f, s)$	regulated exit time of flight plan f from sector s

PART THREE

L C C R

USER'S MANUAL

1 Introduction

1.1 Acknowledgement

This document concerns the end-user of the LCCR prototype. This document is a user one and it describes LCCR operational facilities: it is aimed at giving the necessary information concerning the way the prototype is to be used. The person who wishes to get technical documentation is prompted to refer to the LCCR reference manual.

1.2 The problematic: reminder

Let us give a short reminder of the context in which LCCR prototype was elaborated. Besides, we will refer to the LCCR prototype by naming it LCCR, so as to make things easier from now on.

The CFMU is given the responsibility to regulate the taking-off of air-planes (we talk more commonly of flight plans) from Europe, so that the different physical sectors and aerodromes should not be overloaded. This charge is done in real time by the air traffic controllers in Brussels. Here, to regulate an air-plane means to delay its departure time, if necessary. The constraint of load and capacity are not the only ones, and there are other constraints such as equity constraints (concerning flight plans with same departure and same destination), and priorities constraints (concerning flight plans of air-planes presenting different passengers capacity).

2 What LCCR proposes

So far, this regulation mission is given to the CASA system, which works with slots allocation. LCCR proposes to make up this regulation, regarding the main target, which is to regulate all the flight plans over all the sectors. This regulation is obviously a simulation.

2.1 What LCCR is not

LCCR is absolutely not a real-time application, since it was not designed for. The data concerning the flight plans are given as an entry to LCCR; nevertheless, the data resulting from the regulation made by LCCR is never given back to the system that provided the entry data. However, this does not imply that it would not be feasible with the technology used in LCCR...

2.2 LCCR purpose

LCCR purpose is to provide a decision help application for the CFMU controllers: thus, for a given day and all the flight plans scheduled during that day by the air companies, LCCR proposes a regulation simulation all over Europe, restrictively on the flight plans scheduled to be departed on that given day. This regulation is limited to the sectors, even if the aerodromes curfew constraint is taken into account; no regulation is performed on the aerodromes otherwise. To be a decision help application, on the one side it presents the demand as well on charts and on lists, on the other side, it presents the result of regulation. A particular effort was brought concerning the different tools of monitoring, so as to enable the end-user (an air traffic controller) to determine quickly what flight plan or what sector is mostly responsible for a given delay.

3 The user and the environment

We describe in this section the conditions and the resources required, so that the LCCR prototype can run properly.

3.1 The user

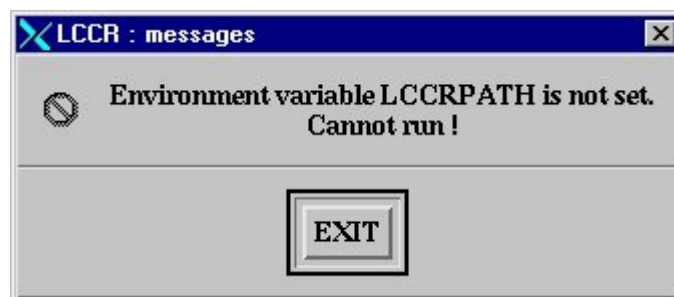
LCCR is a single user application: no particular thing is to be said about that. There is no particular profile per end-user, so that every potential end-user shares the same environment. Note that the parameters (different from the data) modified inside LCCR are saved in preferences files.

Moreover, LCCR is a single document application, which means that it can only handle one set of data at the same time: this set of demand data represents the entry data of the regulation problem for a given date DD.MM.YYYY.

3.2 The application global environment

Some special attention is to be brought on a environment variable that should be set correctly before starting LCCR. This variable's name is **LCCRPATH** and it should point to the directory where the COFEE environment data (environment is to be thought in terms of regulation) extracted lie. We call this directory the LCCR path, and in the future, every directory will be referred relatively to that root path.

In wrong cases, LCCR issues two kinds of error message boxes:



LCCRPATH environment variable not set



LCCRPATH environment variable badly set

3.2.1 **Possible confusion on the word *extraction***

So that the reader makes no confusion, we should warn her that we often use the same word for two different things. Indeed, when we talk about *extraction*, it can refer either to COFEE data environment extraction via the software COFEE, or to the extraction available in the LCCR prototype to translate the COFEE data environment and the ALL_FLIGHTS data flight plans into the LCCR entry demand data. In the future, we talk of COFEE extraction in the first case, and of LCCR extraction in the second case.

3.2.2 **The permanent data files**

LCCR uses two types of demand data files as an entry for the loading. Once some LCCR extraction has been completed, the end-user can load the LCCR demand data produced by this extraction. However, LCCR needs the

following files placed in directory **LCCR_ALWAYS**, so as to complete properly the LCCR extraction, as well as the data loading:

- **aerodromes_default_capacities.lccr**, **collapsed_sectors_default_capacities.lccr** and **elementary_sectors_default_capacities.lccr** for the LCCR extraction; these files are used when the extracted COFEE files do not provide any capacity for the corresponding item;
- **categories.lccr** for the loading.

3.2.3 The COFEE environment data files

These files should be present in the directory named **JYYYYMMDD**, which gathers the extracted COFEE data of the environment corresponding to the date DD.MM.YYYY (for instance, J19990702 for the day 02.07.1999). The exhaustive list of the files is:

- **ACTP.sst**, **ACTPIDEN.sst** for the aircraft types;
- **AD.sst**, **ADTINFO.sst**, **ADUA.sst** for the aerodromes;
- **CF.sst**, **CFAT.sst**, **CFCLSC.sst**, **CFELSC.sst**, **CFFCPR.sst** for the configurations;
- **CLSC.sst**, **CLSCAS.sst**, **CLSCCF.sst** for the collapsed sectors;
- **CP.sst**, **CPPE.sst**, **CPTA.sst**, **CPTE.sst** for the capacities;
- **ELSC.sst**, **ELSCCF.sst** for the elementary sectors.

Note that these files are provided thanks to the COFEE software, which should be normally installed on the same machine as the LCCR prototype. COFEE produces these data environment files, through the COFEE data environment extraction module.

3.2.4 The ALL_FLIGHTS flights data file

Moreover, LCCR needs the flight plans description file, which is commonly called the ALL_FLIGHTS data file. For date DD.MM.YYYY, this file should also be present in the directory named **JYYYYMMDD**, and its name should be **FLIGHTS.sst**.

3.2.5 The LCCR files

3.2.5.1 The basic demand

The LCCR demand data files are produced by LCCR extraction operation, and for an extraction of the date DD.MM.YYYY, the following LCCR files are created in the (newly created if necessary) directory **DEMAND_19000101_000000** standing in directory **LCCRYYYYYMMDD** (also created if necessary):

- **aerodromes.lccr** for the aerodromes;
- **aircraft_types.lccr** for the aircraft types;
- **collapsed_sectors.lccr** for the collapsed sectors;
- **elementary_sectors.lccr** for the elementary sectors;
- **flights.lccr** for the flight plans.

3.2.5.2 Other possible demands

LCCR enables the end-user to save the current solution set (data present in memory) into another demand directory named **DEMAND_yyyymmdd_hhmmss** (created in directory **LCCRYYYYYMMDD** corresponding to date DD.MM.YYYY) where dd.mm.yyyy is the date when the data are saved, hh:mm:ss the corresponding time.

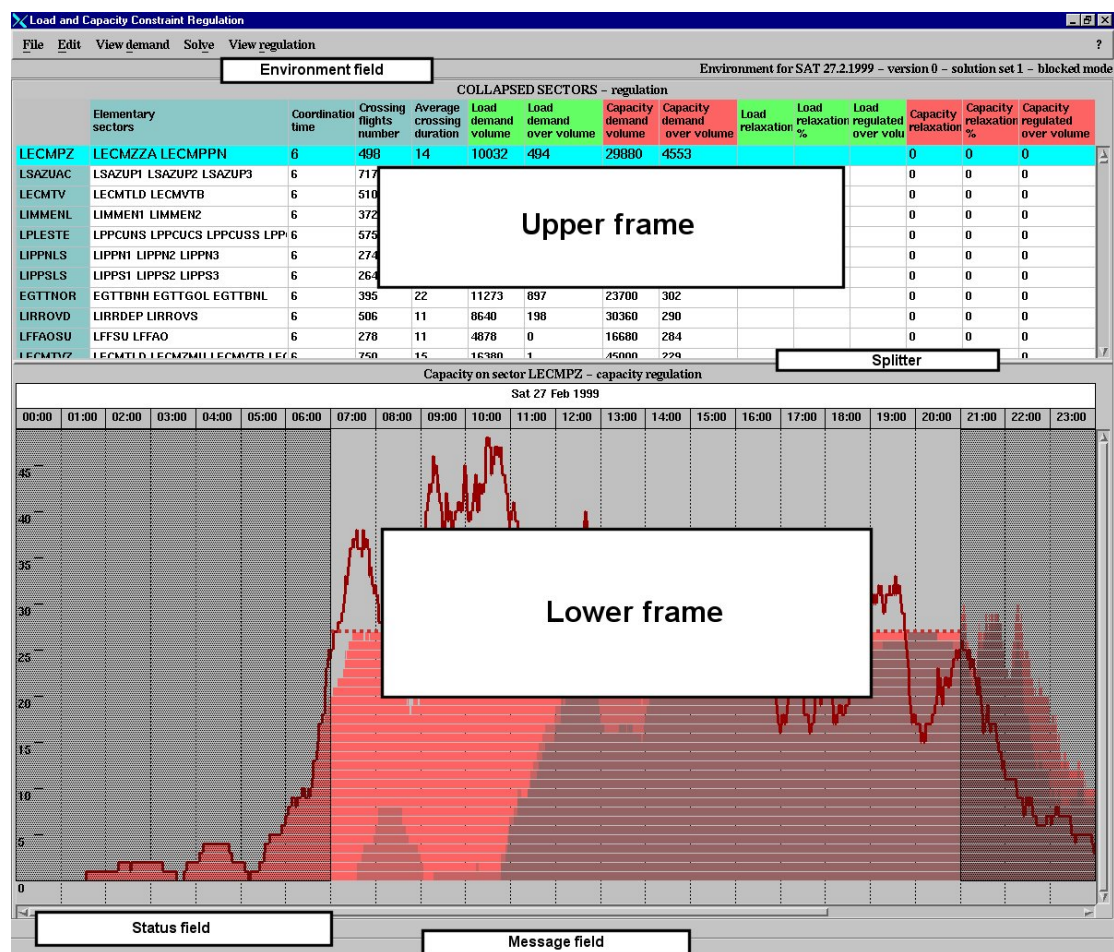
4 The Graphic User Interface

The Graphic User Interface (GUI) is the main frame of the application. We first describe the overall layout, then the different menus, the editable lists and the diagram charts.

4.1 Overall layout

The application is composed by a main window with menus, and a splitter, which divides the main window into two dependently resizable frames (the upper frame and the lower frame). Moreover, there are three special text fields to give some relevant information about the state of the application: the environment field, the status field, the message field.

Some message boxes are displayed to allow the end-user to confirm actions, abort actions, enter some needed value...



LCCR GUI overall layout

4.2 The menus

The menus allow the end-user to perform some actions described bellow. However, we notify the reader that some actions can also be triggered through the keyboard (by shortcut or by accelerator key). For instance, the function <File.Open> can be triggered in three manners:

- either the end-user presses the <File> menu, and then presses the <Open> function: direct action,
- or she proceeds <Ctrl+O>, just by pressing at the same time <Ctrl> and <O> keys: shortcut,

- or she first proceeds <Alt+F> (to open the <File> menu) and then presses the <O> key (to perform the <Open> action) : accelerator key. Each time a shortcut exists, it is displayed next to the corresponding menu item. The accelerator key are underlined. Moreover, sometimes, certain items corresponding to functions in the menu are disabled: they are disabled when they should not be activated, just to prevent the end-user from using them.

<u>P</u>arameters	Alt+P
<u>V</u>iew statistics	Alt+B
<u>V</u>iew <u>c</u>harts	Alt+C
Forget solution	
<u>E</u>xport statistics	

Menu with variably enabled functions

4.2.1 File

This menu deals with a global handling of the entry data.

<u>E</u>xtract	
COFEE settings	
<u>O</u>pen	Ctrl+O
<u>S</u>ave	Ctrl+S
<u>S</u>ave solution	
<u>C</u>lose	Ctrl+C
<u>L</u>CCR settings	Ctrl+L
<u>P</u>references	Ctrl+P
<u>E</u>xit	Ctrl+X

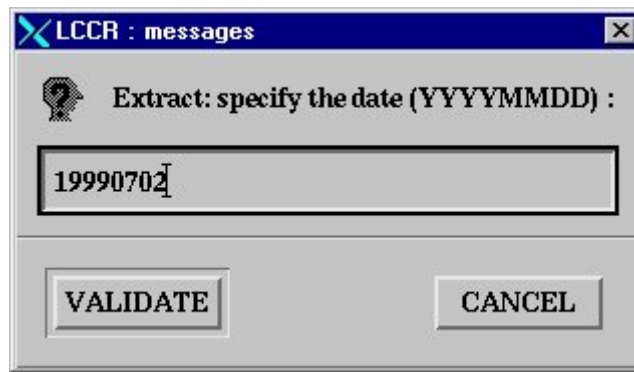
<File> menu

4.2.1.1 COFEE

This part concerns the COFEE extraction and setting.

4.2.1.1.1 Extract (from COFEE & ALL FLIGHTS)

Function that enables the end-user to transform the COFEE data into the LCCR data. The user is asked to enter the date DD.MM.YYYY on which this conversion should be done (the format is YYYYMMDD), via a dialog box. It is possible to cancel the extraction before it is started by pressing the "CANCEL" button. LCCR also displays the COFEE settings panel so as to enable the end-user to specify the corresponding parameters. If the end-user wishes its own modifications performed on that panel to be effective, she needs to call the <APPLY> function on it (in that case or when she presses the <CLOSE> button, it is normal that the panel should disappear).



<File.Extract>: extraction date dialog box

4.2.1.1.1.1 Files required

Before extracting, LCCR needs the COFEE environment and the ALL_FLIGHTS flights data to be present in directory **JYYYYMMDD** (see The COFEE environment data files and The ALL_FLIGHTS flights data file for detail).

4.2.1.1.1.2 Demand files created

LCCR creates the directory named **LCCRYYYYMMDD** if necessary and creates the demand data files in the newly created (if necessary) directory named **DEMAND_19000101_000000**. In this directory, LCCR creates the following files (see The basic demand for more detail):

- **aircraft_types.lccr**,
- **collapsed_sectors.lccr**,
- **demand_info.lccr**,
- **elementary_sectors.lccr**,
- **flights.lccr**,
- **preferences.lccr**.

4.2.1.1.1.3 Warning files issued

Besides, some warning files are generated during this operation. It is important that the files that are generated by this function should be write-enabled ! Otherwise, LCCR cannot write the information on them. These files are generated in the same directory as the one where the COFEE and ALL_FLIGHTS data files are present, that is to say in directory named **JYYYYMMDD**. We list these files and their meaning.

- **COFEE_aerodromes_not_found.lccr**: aerodromes used in the description of a flight plan (departure or/and arrival) but not present in COFEE files.
- **COFEE_aerodromes_without_capacity_defined.lccr**: aerodromes without any capacity defined on the day of the extracted COFEE files for the extraction day: in this case, LCCR uses the capacity in file **aerodromes_default_capacities.lccr**.
- **COFEE_aircraft_types_not_found.lccr**: aircraft types used in the description of a flight plan but not present in COFEE files for the extraction day.
- **COFEE_collapsed_sectors_without_capacity_defined.lccr**: collapsed sectors with an open period on which the COFEE extracted files do not provide any capacity for the extraction day: in this case, LCCR uses the capacity in file **collapsed_sectors_default_capacities.lccr**.

- **COFEE_elementary_sectors_never_open.lccr:** elementary sectors never open during the extraction day, that is to say, with no open period during the extraction day.
- **COFEE_elementary_sectors_not_found.lccr:** elementary sectors used in the description of a flight plan but not present in COFEE files for the extraction day.
- **COFEE_elementary_sectors_not_fully_open.lccr:** elementary sectors that are not always open during all the day of the extraction, that is to say, for at least one period of time of that day: that means that this elementary sector has the property not be collapsed in any activated collapsed sector, neither to be activated during that period.
- **COFEE_elementary_sectors_without_capacity_defined.lccr:** elementary sectors with an open period on which the COFEE extracted files do not provide any capacity for the extraction day: in this case, LCCR uses the capacity in file **elementary_sectors_default_capacities.lccr**.
- **COFEE_extraction_statistics.lccr:** file that gathers different information concerning the extraction.
- **COFEE_flights_crossing_never_open_elementary_sector.lccr:** flight plans kept for the extraction day that cross at least one elementary sector never open during the extraction day.
- **COFEE_flights_crossing_not_fully_open_elementary_sector.lccr:** flight plans kept for the extraction day that cross at least one elementary sector not fully open during the extraction day.
- **COFEE_flights_not_kept.lccr:** flight plans not kept for the extraction day: in addition of the flight plans that are scheduled to take off the day before the extraction day (which are not listed in **COFEE_flights_not_kept.lccr**), these flight plans are not kept because they have the same call-sign as another, and that they are scheduled to take off or to land in the same time as the flight plan with the same call-sign. In this case, the first flight plan encountered in **FLIGHTS.sst** is kept, the other is not.
- **COFEE_flights_with_gaps.lccr:** flight plans kept for the extraction day that present a gap of time between two consecutive elementary sectors crossings.
- **COFEE_flights_with_multiple_definition.lccr:** flight plans kept for the extraction day that do not have a unique call-sign. When LCCR extraction finds a flight plan that will be kept and with a call-sign already used for another flight plan, it postfixes the call-signs of the two flight plans with a "#N" where N is equal to 1 for the first one, N is equal to 2 for the second one. If, in the future, LCCR extraction finds a third flight plan using the same former call-sign, it postfixes its call-sign with a #3, and so on.
- **COFEE_flights_with_no_elementary_sector_crossed.lccr:** flight plans kept for the extraction day that do not cross any elementary sector.
- **COFEE_flights_with_same_time_crossing.lccr:** flight plans kept for the extraction day that cross at the same time two different elementary sectors.
- **COFEE_flights_with_unknown_aircraft_type.lccr:** flight plans kept for the extraction day that uses an undefined aircraft type in the COFEE extracted files. In this case, LCCR extraction creates an aircraft type with the same ICAO code and adds it to the file **COFEE_aircraft_types_not_found.lccr**.

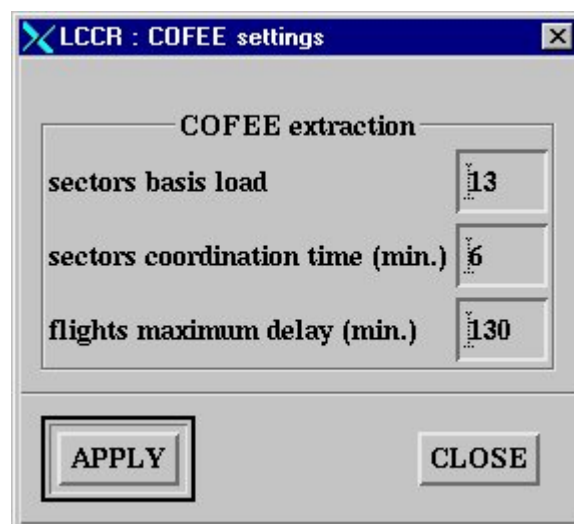
- **COFEE_flights_with_unknown_arrival_aerodrome.lccr**: flight plans kept for the extraction day that land on an undefined arrival in the COFEE extracted files. In this case, LCCR extraction creates an aerodrome with the same code and adds it to the file **COFEE_aerodromes_not_found.lccr**.
- **COFEE_flights_with_unknown_departure_aerodrome.lccr**: flight plans kept for the extraction day that take off from an undefined departure in the COFEE extracted files. In this case, LCCR extraction creates an aerodrome with the same code and adds it to the file **COFEE_aerodromes_not_found.lccr**.
- **COFEE_flights_with_unknown_elementary_sector_crossed.lccr**: flight plans kept for the extraction day that cross an undefined elementary sector in the COFEE extracted files. In this case, LCCR extraction creates an elementary sector fully open with the same code and adds it to the file **COFEE_elementary_sectors_not_found.lccr**.

LCCR checks various things during that stage; among these things, if a flight crosses consecutively the same elementary sector, it is considered to cross it only once, the entry and exit times being collapsed accordingly. The LCCR files created are generated in directory **LCCRYYYYMMDD/DEMAND_19000101_000000**. Note that once extraction finished, no data is kept in memory: if the end-user wants to read the LCCR files generated, she needs to explicitly perform it (through the <File.Open> function).

4.2.1.1.2 COFEE settings

This function displays a panel that enables the end-user to define the LCCR extraction parameters. These parameters are described as followed.

- The basic load: this is the basis load applied to all the sectors (elementary and collapsed) and it is noted **basis_load**. This parameter is used on the sectors extracted by LCCR as described in the sector normalisation function (see Sectors load normalisation).
- The co-ordination time: this is the default co-ordination time applied on all the sectors.
- The flight plans maximum delay: this is the maximum flight plans delay authorised applied on all the flight plans (except for the exempted flight plans that are saved with a null maximum delay authorised).



COFEE settings panel

It is necessary that the <APPLY> should be pressed so as LCCR takes the modifications performed by the end-user into account in the future. When <APPLY> or <CLOSE> is pressed, the panel disappears.

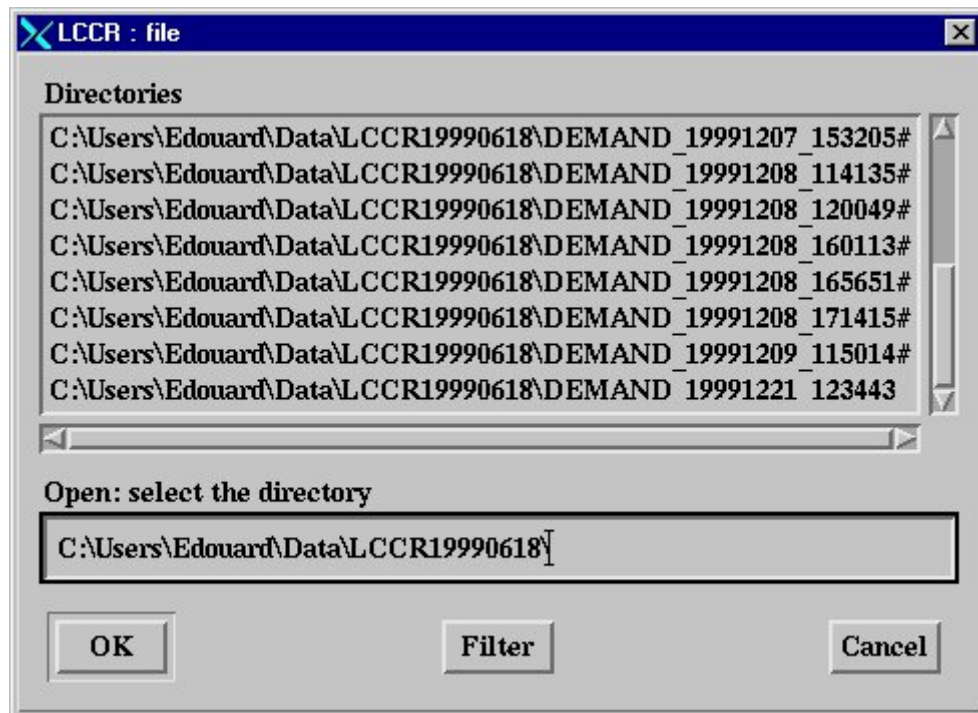
4.2.1.2 LCCR

This part concerns the LCCR reading, saving, closing and setting.

4.2.1.2.1 Open: <Ctrl+O>

Function that enables the end-user to load the entry demand data into memory. LCCR asks the end-user to select the directory in which the data are saved: for that purpose, it displays a selection file box open at the root path directory, displaying all the **LCCRYYYYMMDD** directories, containing all the **DEMAND_yyyymmdd_hhmmss** directories holding the data. When this name is followed by a #, the corresponding directory holds as well the information concerning a solution. dd.mm.yyyy stands for the date when the data were saved (the day when the solution was found when #) and hh:mm:ss stands for the time when the data were saved (the time when the solution was found when #).

During this operation LCCR loads into memory the LCCR files from directory named **LCCRYYYYMMDD/DEMAND_yyyymmdd_hhmmss**. Thus, this function enables the end-user to open demand data with or without regulation (solution) associated.



<File.Open>: demand (and regulation if #) data directory selection box

If the end-user selected correctly a directory, LCCR loads the corresponding data in memory, as well as the solution results if necessary.

4.2.1.2.1.1 Open demand data

At the end of the demand data loading, LCCR is in modify and insert mode and the current solution set is the modification solution set.

4.2.1.2.1.2 Open demand data and regulation

At the end of the demand data and regulation loading, LCCR is in blocked mode and the current solution set is the modification solution set (the solution loaded is present in memory).

4.2.1.2.2 Save: <Ctrl+S>

Function that saves on the hard disk the data corresponding to the current solution set in memory. If the data in memory concern the date DD.MM.YYYY, the data are saved in a newly created directory (standing in **LCCRYYYMMDD**) named **DEMAND_yyyymmdd_hhmmss** where dd.mm.yyyy stands for the date when the demand data are saved and hh:mm:ss stands for the corresponding time. The environment field is updated.

4.2.1.2.3 Save solution

Function that saves the current solution set in memory (provided there is a solution present in memory for it. A new directory named **SOLUTION_yyyymmdd_hhmmss** is created (created in directory **LCCRYYYMMDD** where DD.MM.YYYY is the day of the set of data for which regulation was performed), where yyyy.mm.dd is the date when the solution was found and hh:mm:ss is the corresponding time. The solution can be re-opened in the future through the <File.Open> function. The environment field is updated.

4.2.1.2.4 Close: <Ctrl+C>

Function that discards the current data from memory and also the solution sets. Once this function has been proceeded, no more (demand and optionally regulation) data are present in memory. Note that no set of data can be open until the previous set of date has been closed.

4.2.1.2.5 LCCR settings: <Alt+L>

LCCR prevents the end-user from modifying these parameters in any mode different from the modify and insert mode. This function displays the LCCR setting panel, which enables the end-user to set the following parameters.

- Round-trip gap: these two fields correspond to the minimum (called **round_trip_mini**) and maximum (called **round_trip_maxi**) time (expressed in minute) between the scheduled arrival time of a first leg flight plan and its associated second leg flight plan scheduled departure time.
- Elementary sector capacity unit: this field corresponds to the amount of time (expressed in minute) used to express the capacity in LCCR. We refer it as the parameter **elementary_sector_capacity_unit**. For instance, if this value is equal to 60 (the default value), it means that all the capacities are hourly capacities, if it is equal to 30, the capacities are half-hourly capacities.
- Collapsed sector capacity unit: same thing as for the elementary sector, but applied on the collapsed sectors. We refer it as the parameter **collapsed_sector_capacity_unit**.



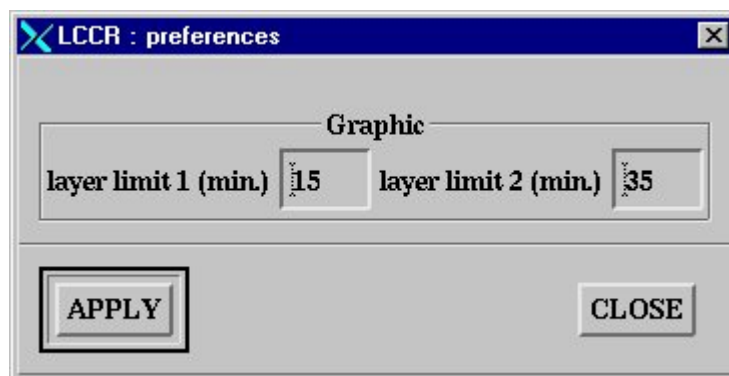
LCCR settings panel

It is necessary that the <APPLY> should be pressed so as LCCR takes the modifications into account in the future. When the end-user presses the <APPLY> or the <CLOSE> button, the panel disappears.

4.2.1.3 Preferences

Function that displays the preferences. These preferences only concern the charts and the layers displayed.

- Layer limit 1: this field represents the first limit `limit_layer1` used to build the graphical layers of a chart diagram representing the profile of a sector; it is also used when LCCR computes some statistics on a solution. To know exactly what this parameter represents, refer to the paragraph dealing with the charts diagrams (see Show/hide layers).
- Layer limit 2: same kind of applications as for the layer limit 1. It is noted `limit_layer2`.



LCCR preferences panel

Some additional preferences are used in LCCR, such as the fact that it displays or not the legend of a chart diagram for example, and all these preferences are saved each time the end-user saves the data, into a file named **preferences.lccr**.

It is necessary that the <APPLY> should be pressed so as LCCR takes the modifications into account in the future. When the end-user presses the <APPLY> or the <CLOSE> button, the panel disappears.

4.2.1.4 Exit: <Ctrl+X>

This function enables the end-user to quit LCCR. The end-user should save the (demand and optionally the regulation) data before leaving if she wants to be able to recover them in a next session of LCCR.

4.2.2 Edit

For this paragraph, we consider that a set of demand data has been loaded into memory through the command <File.Open>.

<u>F</u>light	Ctrl+1
<u>A</u>erodrome	Ctrl+2
<u>A</u>ircraft type	Ctrl+3
<u>E</u>lementary sector	Ctrl+4
<u>C</u>ollapsed sector	Ctrl+5
<u>S</u>ector	Ctrl+6
<u>K</u>eep solution set	Alt+K
<u>D</u>iscard solution set	Alt+D
<u>V</u>isualize solution set...	Alt+V
<u>A</u>ctivate <u>m</u>odify mode	Alt+M
<u>A</u>ctivate modify & insert mode	
<u>A</u>pply global value	

<Edit> menu

This menu enables the end-user to search for a specific kind of object (aerodrome, aircraft type, sector) and to display it in the upper frame, not having to view the full corresponding list. It also enables LCCR to swap between different modes of use, and to apply global values to the objects.

Note that when the end-user searches for a specific kind of object, if this object exists, the whole list representing all the objects of the same type may be not displayed. There are two cases: either the whole list exists and it is displayed, or it does not exist, and in this case, the list displayed is only composed by one row, the one representing the object. In any of these two cases, the object is selected (we say that an object is selected when one row representing that object in a list is selected through its row header and consequently highlighted).

	Collapsed sectors	Coordination time	Crossing flights number	Average crossing duration	Load demand volume	Load demand over volume	Capacity demand volume	Capacity demand over volume
LECMPPN	LECMDFZ LECMN LECMNE LECMPZ	6	378	11.00	6427	0	22680	0
LECMSTG	LECMN LECMSB	6	267	24.29	8088	63	16020	14
LECMTLD	LECMS LECMTV LECMTVZ LECMZT	6	353	9.82	5586	0	21180	0

A list example

4.2.2.1 Search and edit an object

For all the functions described in this paragraph, if the end-user presses the <VALIDATE> button without having fulfilled the dialog box text field, the search is cancelled. Moreover, when the end-user has fulfilled this text field, she can directly press the <ENTER> key, so as to get the same effect as the <VALIDATE> button.

4.2.2.1.1 Flight: <Alt+F>

When this function is triggered, the end-user is asked to enter a flight plan call-sign, and if the corresponding flight plan exists, it is displayed and selected in a list.

4.2.2.1.2 Aerodrome: <Alt+A>

When this function is triggered, the end-user is asked to enter an aerodrome code, and if the corresponding aerodrome exists, it is displayed and selected in a list.

4.2.2.1.3 Aircraft type: <Alt+T>

When this function is triggered, the end-user is asked to enter an aircraft type code, and if the corresponding aircraft type exists, it is displayed and selected in list.

4.2.2.1.4 Elementary sector: <Alt+E>

When this function is triggered, the end-user is asked to enter an elementary sector code, and if the corresponding elementary sector exists, it is displayed and selected in a list.

4.2.2.1.5 Collapsed sector: <Alt+C>

When this function is triggered, the end-user is asked to enter a collapsed sector code, and if the corresponding collapsed sector exists, it is displayed and selected in a list.

4.2.2.1.6 Sector: <Alt+S>

When this function is triggered, the end-user is asked to enter a sector (elementary or collapsed) code, and if the corresponding sector exists, it is displayed and selected in a list.

4.2.2.2 The notion of solution set

Before explaining the next functions, we have to explain the notion of solution set used through LCCR. A solution set is composed by a demand, a set of solving parameters and an optional regulated information (solution of the solver).

LCCR is able to store up to three solution sets (also called the solution sets for storage) in memory at the same time. In addition, LCCR offers a special additional solution set, that we call the modification solution set: when the end-user changes the demand data or the solving parameters, she always changes the modification solution set. Moreover, LCCR always displays the (demand and optionally the regulation) data corresponding to a given solution set, that we call the current solution set.

We say that a solution set for storage is free when no (demand and optionally regulation) data are stored in it; if this not the case, we say that the solution set is being used. Each solution set for storage is given an identifier which is a number (ranging from 1 to 3). When the current solution set is one of the solution sets for storage, LCCR always displays this information in the environment field.

4.2.2.2.1 Different modes

LCCR works in four possible modes; we describe exhaustively these modes. Each one of these modes correspond to an editable state that we sum up at

the end of this document. LCCR cannot be simultaneously in two different modes. The current mode is always reminded in the environment field.

- Modify and insert mode: when the current solution set is the modification solution set, that no solution set for storage is used and that no solution is present in memory for that set, we say that LCCR is in modify and insert mode. It is the case, for instance, when the end-user calls the <Edit.Activate modify & insert mode> function.
- Insert mode: when the current solution set is the modification solution set, that no solution set for storage is used, that no solution is present in memory for that set and that an object is being created, we say that LCCR is in insert mode. It is the case, for instance, when LCCR is in modify and insert mode and that the end-user creates a new object through the <Insert record> function.
- Modify mode: when the current solution set is the modification solution set, that one solution set for storage is being used and that no solution is present in memory for that set, we say that LCCR is in modify mode. It is the case, for instance, when the end-user performs the <Edit.Activate modify mode> function.
- Blocked mode: when a solution is present in memory for the current solution set, we say that LCCR is in blocked mode. It is the case, for instance, when the end-user opens a solution set with solution associated through the <File.Open> function.

4.2.2.2.2 Keep solution set: <Alt+K>

Note that this function is only enabled when the current solution set is the modification set: no solution needs to be present for that solution set, that is to say that the end-user is allowed to keep in memory a solution set without any solution found for it.

This function keeps the current solution set (regulated or not) in memory. If some solution set for storage is free, LCCR automatically stores the current solution set in the first solution set for storage not used (with the smallest identifier). If there is no more free solution set for storage, LCCR asks the user which solution set for storage to overwrite: all the formation information kept in the solution set for storage selected will be definitively lost.

The current solution set becomes the modification solution set initialised with the demand just kept (modify mode).

4.2.2.2.3 Discard solution set: <Alt+D>

Note that this function is only enabled when the current solution set is one of the three solution set for storage.

This function discards (if confirmed) the current solution set for storage: all the information it contained is definitively lost and this solution set becomes free.

The current solution set becomes the modification set (modify mode if at least one solution set for storage is used, modify and insert mode otherwise).

4.2.2.2.4 Visualise solution set...: <Alt+V>

Note that this function is enabled only when there is more than one solution set for storage used.

This function enables the end-user to change the current solution set: the end-user is asked which solution set for storage to select if there is more than one solution set for storage used. When there is just one solution set for storage used, LCCR automatically selects it.

The current solution set becomes the solution set for storage selected (blocked mode).

4.2.2.2.5 Activate modify mode: <Alt+M>

Note that this function is only enabled when the current solution set is one of the three solution sets for storage.

This function enables the end-user to modify the demand data, for a new solving for instance: the current solution set becomes the modification set and the end-user is allowed to change certain objects, as well as the solving parameters.

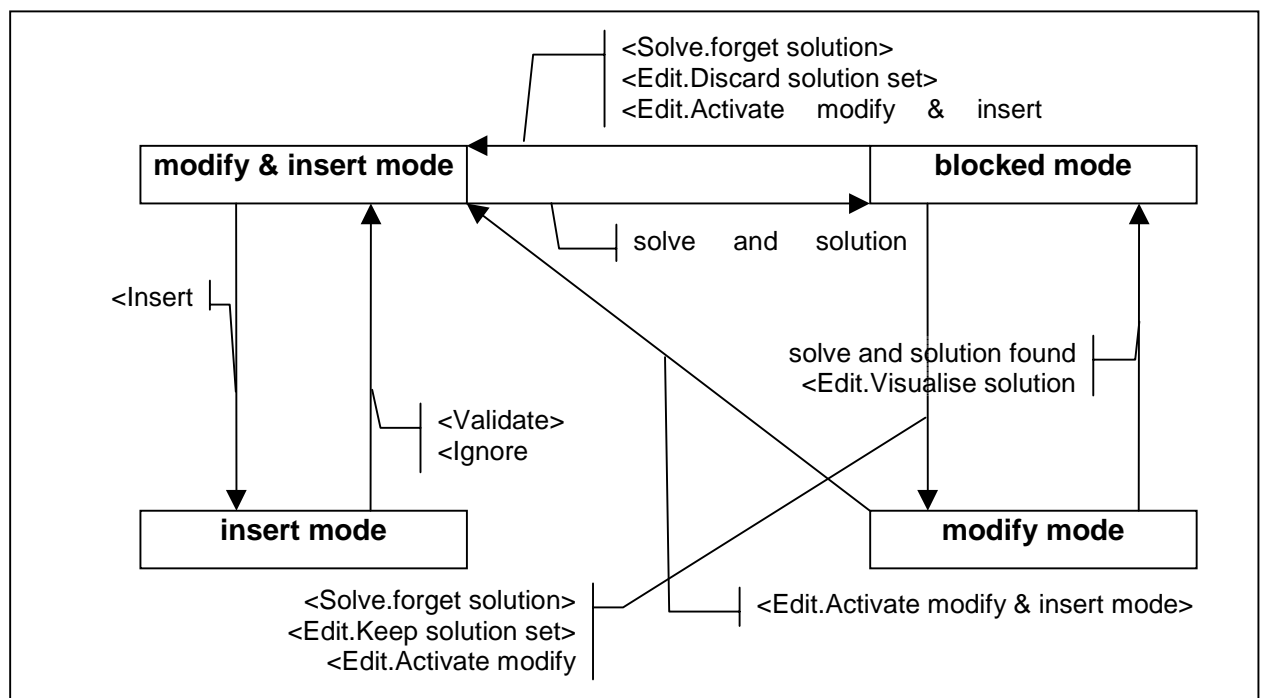
The current solution set becomes the modification solution set (modify mode if at least one solution set for storage is used, modify and insert mode otherwise).

4.2.2.2.6 Activate modify & insert mode

Note that this function is only enabled when at least one of the three solution sets for storage is used or when a solution is present for the modification solution set.

This function enables the end-user to discard all the solution sets for storage, and to insert or delete objects in the future.

The current solution set becomes the modification solution set (modify and insert mode).



State diagram of the various modes

4.2.2.3 Apply global value

These functions provides a facility to apply globally values to the objects.

4.2.2.3.1 Sectors co-ordination time

This function enables the end-user to change the individual co-ordination time of all the sectors. LCCR asks the end-user to enter a valid co-ordination

time value; then it applies it to all the sectors. The old values will be definitively lost.

4.2.2.3.2 Sectors load normalisation

This function enables the end-user to re-compute the different load limit profiles for all the sectors. LCCR asks the end-user to enter a valid basis load value used as the basis load normalisation. The old values will be definitively lost.

We now explain the way LCCR computes the load limit profile values according to this basis load value that we note **basis_load**. For a given sector, and on all its open periods, LCCR looks for the (non null and non infinite) capacity lowest value: let us call **minimum_capacity** this value.

It then applies the **basis_load** as local load limit in the open periods where the local capacity limit is equal to **minimum_capacity**. For the other periods, the new local load limit is increase by 1 unit if the local capacity is strictly less than 15 % of the **minimum_capacity**, by 2 units if the local capacity is strictly greater than 15 % but strictly less than 25 % of the **minimum_capacity**, and it is doubled if the local capacity exceeds or equals 25 % of the **minimum_capacity** (in this case, LCCR considers that the sector is split into two sectors with one controller monitoring each sector, that is why the local load limit is doubled). This normalisation was performed so as to harmonise the load in accordance with the capacity.

4.2.2.3.3 Flight plans category delay

This function enables the end-user to change the individual flight plans maximum delay authorised. LCCR asks the end-user is she confirms this action; if yes, it applies it to all the flight plans: the new maximum delay authorised on a given flight plan will be the maximum delay of the category its aircraft type belongs to. The old values will be definitively lost.

4.2.3 View demand

For this paragraph, we consider that a set of data has been loaded into memory through the command <File.Open>. This menu concerns the editable lists of objects display. The corresponding editable list is displayed on the upper frame of LCCR main frame. When one the functions of that menu is called, we say that LCCR is in demand view.



4.2.3.1 Flights...

4.2.3.1.1 All flights

This function displays all the flight plans.

4.2.3.1.2 Round-trip

This function displays all the round-trip flight plans.

4.2.3.2 Aerodromes

This function displays all the aerodromes.

4.2.3.3 Categories

This function displays all the categories.

4.2.3.4 Aircraft types

This function displays all the aircraft types.

4.2.3.5 Elementary sectors

This function displays all the elementary sectors.

4.2.3.6 Collapsed sectors

This function displays all the collapsed sectors.

4.2.4 Solve

This menu concerns LCCR solver.

Parameters	Alt+P
View statistics	Alt+B
View charts	Alt+C
Forget solution	
Export statistics	

<Solve> menu

4.2.4.1 Parameters

This function displays the solving parameter panel. This dialog box can be used as well to launch a new solving, as to visualise the solving parameters used. We describe from the top left to the bottom right the different fields of this panel.

LCCR : solving parameters

Constraints used

☐ elementary ☐ equity ☐ curfew
☐ collapsed ☐ round-trip

Optimisation

☒ minimise delayed flights number
☒ minimise delay per flight
☒ minimise delay per delayed flight

Quality

flight percentage : 6
quality 603

Global parameters

coordination time ☒ individual ☐ global duration (min.) 7
maximum delay ☒ individual ☐ per category
round-trip trigger (min.) : 10 equity trigger (min.) : 5

Relaxation

<input checked="" type="checkbox"/> on flights delay	step (%) 12	maximum increase (%) 50
<input type="checkbox"/> on capacity	step (%) 5	maximum increase (%) 20
<input type="checkbox"/> on load	step (%) 7	maximum increase (%) 28

Priorities handled

☒ equity
☒ round-trip
☒ category

Regulation type

☐ capacity
☐ load

SOLVE **CLOSE** **APPLY**

LCCR solving parameters panel

Once the parameters correctly set, the end-user can press the <APPLY> button, so that LCCR takes into account the new parameters: this button is disabled when LCCR is in blocked mode (the <SOLVE> button as well). It is possible to cancel any change not yet applied by pressing the <CLOSE> button. When the end-user presses the <SOLVE> button, LCCR applies the parameters and then launches the solver. In this case, LCCR first posts the constraints (stage during which no abortion is made possible), and then starts to place the flight plans: the end-user can interrupt the solving by pressing the <ABORT> button displayed. Note that the refreshing of the graphical layout is slower when solving. Moreover, all the menus are unavailable during solving: the end-user cannot use LCCR facilities during solving !

If LCCR does not find any solution, the end-user is notified; otherwise, LCCR displays the statistics panel at the end.



LCCR solving abortion dialog box

4.2.4.1.1 Constraints used

This frame gathers all the available constraints that LCCR can handle. It is up to the end-user to select or deselect the constraints that she wants to be respected. These constraints are.

- The elementary sectors constraint on the ability (capacity or/and load): this constraint imposes that the abilities limit profiles should be respected on all the elementary sectors.
- The collapsed sectors constraint on the ability (capacity or/and load): this constraint imposes that the abilities limit profiles should be respected on all the collapsed sectors.
- The equity constraint on the flight plans using the parameter **equity_trigger** settable through this panel. This constraint imposes on all the flight plans couples f_1 and f_2 departing from the same aerodrome in that chronological order, and arriving at the same aerodrome, that after regulation, f_1 is allowed to take off after f_2 only if it does not take off more than **equity_trigger** minute after f_2 .
- The round-trip constraint on the flight plans using the parameter **round_trip_trigger** settable through this panel. This constraint imposes on all the round-trip flight plans couples f_A and f_B , that after regulation, the difference of delay between f_A and f_B must be less than **round_trip_trigger** minute. In other words, this constraint imposes that the former gap between the arrival time of the first leg flight plan f_A and the departure time of the second leg flight plan f_B should be respected (greater or equal than the estimated one minus **round_trip_trigger** minute) after regulation.
- The curfew constraint on the aerodromes. This constraint imposes that no flight plan is allowed to depart from an aerodrome during the periods when this aerodrome has a null departure capacity, and that no flight plan is allowed to arrive at an aerodrome during the periods when this aerodrome has a null arrival capacity.

When a constraint is enabled, LCCR posts it accordingly before solving. For any detail concerning these constraints, please refer to the LCCR reference documentation.

4.2.4.1.2 Priorities handled

This frame gathers all the possible priorities handled during the solving. The various priorities are used to impose a strategy concerning the order in which LCCR tries to place the flight plans. When a priority is enabled, LCCR uses it during the solving.

- The equity priority: when LCCR places a flight plan during the solving, it places as well all the flight plans in equity constraint with it, and estimated to take off before it.

- The round-trip priority: when LCCR places a flight plan during the solving, it places as well its linked flight plan if it belongs to a round-trip flight plan couple, so as to minimise the difference between the regulated and estimated gaps between the first leg arrival time and the second leg departure time.
- The category priority: when LCCR cannot give priority concerning the order in which two flight plans are placed during the solving, LCCR compares the category their aircraft type belong to and give priority to the flight plan with the smallest category number.

For any detail concerning these priorities, please refer to the LCCR reference documentation.

4.2.4.1.3 Optimisation

This frame concerns LCCR solving optimisation. There are three different optimisations available, and exclusively:

1. Minimise the number of delayed flight plans.
2. Minimise the average delay per flight.
3. Minimise the average delay per delayed flight.

According to the criteria, LCCR will perform additional computation during the solving, so as to get the best solution. For any detail concerning the optimisation, please refer to the LCCR reference documentation.

4.2.4.1.4 Quality

This frame concerns LCCR solving quality:

1. The flight percentage field indicates the value of **group_percentage**, used to select a group of flight plans during the solving. This factor corresponds to the percentage of flight plans LCCR takes (compared to the total number of flight plans) for each group placement.
2. The bar represents the quality of the solving referred as **search_quality**. On this factor depends the frequency of the solver strategy refreshing: the higher the corresponding value is, the finer the solving will be, but the longer the solving will be.

For any detail concerning the solving quality, please refer to the LCCR reference documentation.

4.2.4.1.5 Regulation type

This frame enables the end-user to specify what kind of regulation she wants LCCR to perform, non exclusively:

- Capacity: when this button is active, the regulation by capacity is taken into account.
- Load: when this button is active, the regulation by load is taken into account.

Note that, for instance, when the end-user selects the load regulation, and disables the collapsed sectors (in the constraints used), regulation on the collapsed sectors will not be performed by the solver.

For any detail concerning the regulation type, please refer to the LCCR reference documentation.

4.2.4.1.6 Global parameters

This frame gathers the necessary information concerning the global parameters. Note that the individual values are not overwritten by the global parameters: the solver only uses the global parameters (when demanded) for the regulation. Thus, the end-user should be very careful on that point.

- Sectors co-ordination time: the end-user should enable the <individual> button if she wants the solver to use the individual co-ordination time of the sectors, <global> if she wants to use the same global co-ordination time for all the sectors. In this latter case, the end-user should also fill in the <duration> field, so as to specify this global co-ordination time (expressed in minute).
- Flight plans maximum delay: the end-user should enable the <individual> button if she wants the solver to use the individual maximum authorised delay of the flight plans, <per category> if, for each flight plan, she wants to use as a maximum delay authorised the maximum delay of the category its aircraft belongs to.
- Round-trip trigger: this field (expressed in minute) enables the end-user to specify the parameter `round_trip_trigger`.
- Equity-trip trigger: this field (expressed in minute) enables the end-user to specify the parameter `equity_trigger`.

For any detail concerning the global parameters, please refer to the LCCR reference documentation.

4.2.4.1.7 Relaxation

This frame gathers the information concerning the solver relaxation. The end-user should be familiar with the relaxation mechanism in LCCR, so that she can set properly these parameters.

- Flight delay: if this button is disabled, no relaxation is allowed on the flight plans maximum delay. Otherwise, the end-user should fill in the two following fields, which indicate the step `delay_relaxation_step_percentage` and the maximum increase `delay_relaxation_maximum_percentage`.
- Capacity: if this button is disabled, no relaxation is allowed on the sectors capacity limit profiles. Otherwise, the end-user should fill in the two following fields, which indicate the step `capacity_relaxation_step_percentage` and the maximum increase `capacity_relaxation_maximum_percentage`.
- Load: if this button is disabled, no relaxation is allowed on the sectors load limit profiles. Otherwise, the end-user should fill in the two following fields, which indicate the step `load_relaxation_step_percentage` and the maximum increase `load_relaxation_maximum_percentage`.

For any detail concerning the relaxation, please refer to the LCCR reference documentation.

4.2.4.2 View statistics: <Alt+X>

This function enables the end-user to display the statistics panel corresponding to the solution of the current solution set, if there is one.

Statistics – capacity regulation	
Solution found in	274 sec.
Number of flights	13781
Number of flights delayed	1796 (13.0 %)
Total delay	140405 min.
Maximum delay	269 min.
Delay per flight	10 min.
Delay per delayed flight	78 min.
Flights delayed less than 15 min.	326 (18.2 %)
Total delay of flights delayed less than 15 min.	2484 (1.8 %)
Flights delayed between 15 and 35 min.	294 (16.4 %)
Total delay of flights delayed between 15 and 35 min.	7044 (5.0 %)
Flights delayed more than 35 min.	1176 (65.5 %)
Total delay of flights delayed more than 35 min.	130877 (93.2 %)
Maximum delay relaxation	49 %
Number of flights relaxed	76 (4.2 %)
Number of sectors	1823
Maximum capacity relaxation	0 %
Number of sectors capacity-relaxed	0

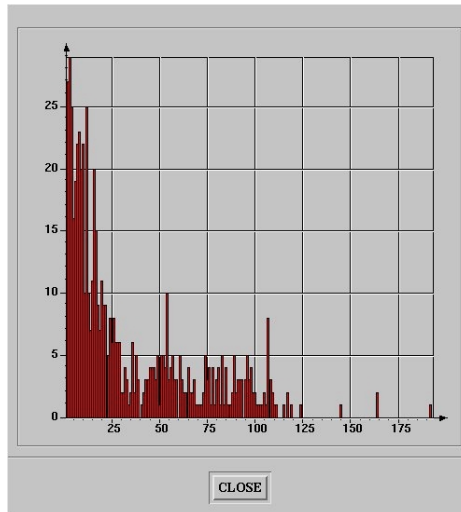
CLOSE

LCCR regulation statistics panel

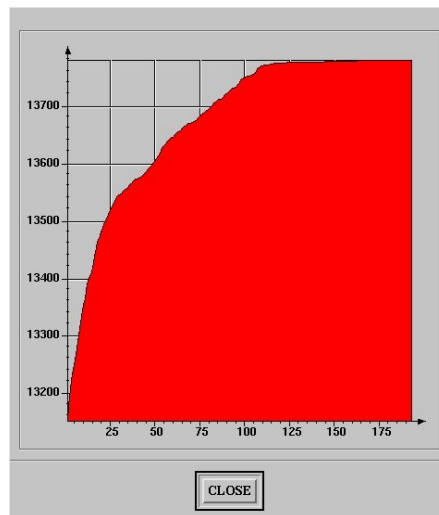
4.2.4.3 View charts: <Alt+Y>

This function enables the end-user to display the two charts corresponding to the solution of the current solution set, if there is one.

- The histogram chart that represents the flight plan delay in the x axis, and the number of flight plans having a delay x in the y axis.
- The cumulative chart that also represents the flight plan delay in the x axis, and the number of flight plans having a delay less or equal than x in the y axis.



LCCR regulation histogram chart



LCCR regulation cumulative chart

4.2.4.4 Forget solution

This function enables the end-user to discard from memory the current solution present for the current solution set, if there is one. This solution is discarded from memory and the current solution set remains the modification solution set. If no solution set becomes being kept, LCCR becomes in modify and insert mode, otherwise, LCCR is in modify mode.

4.2.4.5 Export statistics

This function enables the end-user to export into a file the features of the solution associated to the current solution set, if there is one. This file is created in the directory named **LCCRYYYMMDD** (set of data in memory for date DD.MM.YYYY). The name of the text file is **statistics_yyyymmdd_hhmmss.lccr** where dd.mm.yyyy represents the date when the solution was found and hh:mm:ss represents the time at which the solution was found. This exported file gathers all the parameters used to issue the corresponding regulation, as well as the statistics of the regulation.

4.2.5 View regulation

For this paragraph, we consider that there is a solution present for the current solution set. This menu concerns the non editable lists of objects display. The non editable lists are displayed on the upper frame. Some extra information corresponding to the regulation is displayed on these lists. No object can be modified nor deleted in these lists. When one of the functions of that menu is called, we say that LCCR is in regulation view.



4.2.5.1 Flights

4.2.5.1.1 All flights

This function displays all the flight plans.

4.2.5.1.2 Delayed flights

This function displays all the delayed flight plans.

4.2.5.2 Elementary sectors

This function displays all the elementary sectors.

4.2.5.3 Collapsed sectors

This function displays all the collapsed sectors.

4.2.6 About (F1)

This menu displays global information about LCCR.

4.3 The objects

There are several kind of objects in LCCR. We describe the main objects used throughout the prototype.

4.3.1 Time convention

All times are expressed with 4 digits: "HHMM" stands for HH:MM. Note the convention used in LCCR: when a time corresponds to the day (the date of the set of data) before the regulation day, it is preceded by a "-"; when it refers to the day after, it is preceded by a "+". For instance, if we open a set of data corresponding to the date 02.07.1999, "1200" corresponding to midday on the same day, "-1200" to midday, the 01.07.1999 and "+1200" to midday, the 03.07.1999.

4.3.2 The notion of ability (capacity or/and load)

LCCR handles the notion of ability. A list of abilities is attached to an aerodrome or to a sector (elementary or collapsed), and it designates a capacity or/and a load. An ability is composed by:

- a start time (during the date of the regulation),
- an end time (always during the date of the regulation),
- a capacity or/and a load maximum value for the period delimited by the previous start and the end times.

The notion of ability is used everywhere a maximum ability profile is required, that is to say for the sectors and for the aerodromes. Concerning the aerodromes, only the capacity concept is displayed and used (when it is null, for the curfew constraint).

4.3.3 The flight plan

4.3.3.1 Attributes

A flight plan is composed by:

- a code,
- an aircraft type represented by its code,
- a departure aerodrome represented by its code,
- an arrival aerodrome represented by its code,
- an estimated departure time (before regulation),
- an estimated arrival time (before regulation),
- a status ("N" for normal and "E" for exempted): when exempted, the flight plan cannot be delayed and the solver will not take into account its maximum delay authorised,
- a flight type ("1/1" for a single flight plan, "1/2" for the first leg of a round-trip flight plans couple, "2/2" for the second leg),
- the flight plan linked to it: the code of the other flight plan of its round-trip flight plans couple; empty otherwise,
- its maximum delay authorised (expressed in minute); this attribute does not represent anything for an exempted flight plan,
- its delay calculated (after regulation),
- its relaxation percentage (after regulation): "0" means that there has been no relaxation,
- a list of elementary sectors crossed represented by their code; for each elementary sector crossed, the flight plan structure gathers the physical (not taking into account the sector co-ordination time) estimated entry and exit time: this constitutes the flight route.

Concerning the flight route, a list of sectors is displayed in the lower frame when a flight plan is selected and LCCR displays on the same row:

1. the code of the sector,
2. the type of the sector ("E" for elementary, "C" for collapsed),
3. the physical crossing duration, not taking into account the sector co-ordination time,
4. the estimated entry time (before regulation),
5. the calculated entry time (after regulation),
6. the estimated exit time (before regulation),
7. the calculated exit time (after regulation),
8. the capacity limit profile relaxation on the sector ("Yes" if there has been capacity limit profile relaxation, "No" otherwise),
9. the load limit profile relaxation on the sector ("Yes" if there has been load limit profile relaxation, "No" otherwise).

In this list, when a sector is highlighted, it means that the corresponding flight plan crosses it during at least one minute of its open periods (in demand view, the flight plan is considered to take off at its estimated take off time, in regulation view, the flight plan is considered to take off at its regulated take off time).

	A/C	A/D Dep	ETOT	CTOT	A/D Arr	EAT	CAT	Status	Flight type	Linked flight	Delay maximum	Delay calculated	relaxation %
AFR2140	B733	LFPG	1715	1715	EHAM	1800	1800	N	1/2	AFR2141	180	0	0
Profile : AFR2140													
	Type	Crossing duration	Estimated entry time	Calculated entry time	Estimated exit time	Calculated exit time	Capacity relaxation	Load relaxation					
LFFZDAE	E	0001	1715	1715	1716	1716	No	No					
LFFZDA	C	0001	1715	1715	1716	1716	No	No					
LFFZDAW	E	0005	1716	1716	1721	1721	No	No					
LFFZDA	C	0005	1716	1716	1721	1721	No	No					
LFFTB	E	0010	1721	1721	1731	1731	No	No					
LFEBRUT	C	0010	1721	1721	1731	1731	No	No					
LFFFPW	C	0010	1721	1721	1731	1731	No	No					
LFFRPW	C	0010	1721	1721	1731	1731	No	No					
LFFTENB	C	0010	1721	1721	1731	1731	No	No					
LFFTNB	C	0010	1721	1721	1731	1731	No	No					
EBBUHWS	E	0007	1732	1732	1739	1739	No	No					
EBBUALL	C	0007	1732	1732	1739	1739	No	No					
EBBUHIG	C	0007	1732	1732	1739	1739	No	No					
EBBUWS	C	0007	1732	1732	1739	1739	No	No					
EHSECT3	E	0006	1739	1739	1745	1745	No	No					
EH12345	C	0006	1739	1739	1745	1745	No	No					
EH3+4+5	C	0006	1739	1739	1745	1745	No	No					
EHAMTMA	E	0011	1749	1749	1800	1800	No	No					

A flight plan

This information is the necessary and sufficient information for an exhaustive flight plan description inside LCCR (there is no need to specify the estimated take off date since it is the same as the regulation day).

4.3.3.2 Creation

When LCCR is in modify and insert mode, the end-user can create a new flight plan by calling the <Insert record> function when the demand flight plans list is active (through the <View demand. Flights. All> function).

When inserted by the end-user, all the attributes of a flight plan must be filled in. But before that, the end-user must first fill in the information of the lower frame (the flight route composed by elementary sectors crossings). When finished, she must validate the flight route through the <Validate> function above the lower frame: once the flight route validated, it cannot be modified any longer in the future. Then, the end-user must fill in the information asked for in the upper frame (including the call-sign of the flight plan in the row header). When finished, the end-user must validate the information through the <Validate> function above the upper frame. After this step, the new flight plan is created and LCCR exits from the insert mode (the end-user can abort at any time the insertion of the currently created object by calling the <Ignore insert> function): the call-sign of the flight plan cannot be changed any longer in the future.

4.3.3.2.1 The flight route

Each time the end-user wishes to add an elementary sector to the route, she has to call the <Insert record> function above the lower frame, specify the name of the elementary sector in the row header field, the entry time in, the exit time from that elementary sector (the type field and the crossing time field are not editable on purpose).

When she wants to erase an elementary sector from the route, she just has to call the <Delete record> function above the elementary sector row to delete.

Only when the end-user is satisfied with the global route, she has to call the <Validate> function above the lower frame.

4.3.3.2.2 First or second leg of a round-trip flight plan couple

When the end-user validates a flight plan newly inserted, LCCR looks at all the flight plans already created that may be its first or second leg flight plan, and update correctly the information if it is the case.

We sum up the necessary conditions that LCCR uses to decide whether a couple of flight plans f_A and f_B is a round-trip couple, f_A being the first leg:

1. the call-sign of f_B must be the same as the one of f_A , except that the last digit must be increased by one,
2. the aircraft types of the two flight plans must be the same,
3. f_A arrival aerodrome and f_B departure must be the same,
4. f_B arrival aerodrome and f_A departure must be the same,
5. f_B must be estimated to take off between `round_trip_mini` and `round_trip_maxi` minute after f_A estimated departure time.

4.3.3.3 Modification

When, in modify mode, the end-user wishes to modify an already created flight plan, she just have to edit the cell corresponding to the attribute she wants to change: the modification is automatically validated when she quits the cell edition.

4.3.4 The aerodrome

4.3.4.1 Attributes

An aerodrome is composed by:

- a code,
- a list of capacities.

Concerning an aerodrome, when it is selected, this list of capacities is displayed in the lower frame:

- a list of departure capacities,
- a list of arrival capacities,
- a list of global capacities.

DTTJ	DXXX		EBAW		EBBR		EBBT		EBCI		EBFN		EBKT		EBLG		EBOS	
Opening hours / capacities : EBBR																		
EBBR	G start	G end	Capacity	D start	D end	Capacity	A start	A end	Capacity									
	0000	0600	30	0000	0600	30	0000	2400	32									
	0600	0700	45	0600	0700	37												
	0700	2000	64	0700	2000	32												
	2000	2200	45	2000	2200	37												
	2200	2400	30	2200	2400	30												

An aerodrome

This information is the necessary and sufficient information for an exhaustive aerodrome description inside LCCR.

4.3.4.2 Creation

When LCCR is in modify and insert mode, the end-user can create a new aerodrome by calling the <Insert record> function when the aerodromes list is active (through the <View demand.Aerodromes> function).

When inserted by the end-user, the code of the aerodrome must be filled in. But before that, the end-user must first fill in the information of the lower frame (the capacities of the aerodrome). When finished, she must validate the capacities through the <Validate> function above the lower frame: once the capacities validated, they can be also freely modified in the future. Then, the end-user must fill in the aerodrome code asked for in the upper frame.

When finished, the end-user must validate the information through the <Validate> function above the upper frame. After this step, the new aerodrome is created and LCCR exits from the insert mode (the end-user can abort at any time the insertion of the currently created object by calling the <Ignore insert> function): the code of the aerodrome cannot be changed any longer in the future.

4.3.4.2.1 The capacities

Each time the end-user wishes to add a capacity, she has to call the <Insert record> function above the lower frame, specify the start and end times of the period, the capacity for that period in the column corresponding to the kind of capacity (global, departure, arrival).

When she wants to erase a capacity, she just has to call the <Delete record> function above the capacity row to delete.

Only when the end-user is satisfied with the capacities, she has to call the <Validate> function above the lower frame.

4.3.4.3 Modification

When, in modify mode, the end-user wishes to modify an already created aerodrome, she just has to select the aerodrome, make the necessary modifications on the lower frame where the capacities are displayed, and then validate the modifications by calling the <Validate> function. If the end-user does not validate the modifications, LCCR will not take them into account.

4.3.5 The category

4.3.5.1 Attributes

A category is composed by:

- a number,
- a number of minimum passengers,
- a number of maximum passengers,
- a maximum delay.

This information is the necessary and sufficient information for an exhaustive category description inside LCCR.

In addition, LCCR displays for a given category:

- the number of aircraft types belonging to that category,
- the number of flight plans whose aircraft type belongs to that category.

	Minimum passengers	Maximum passengers	Maximum delay	Aircrafts number	Flights number
1	300	1000	180	111	10710
2	200	299	180	81	2666
3	100	199	180	21	292
4	5	99	180	0	0
5	0	4	180	8	113

The categories

4.3.5.2 No creation

No category can be created.

4.3.5.3 Modification

When, in modify mode, the end-user wishes to modify the maximum delay of a category, she just has to edit the cell corresponding to that attribute: the modification is automatically validated when she quits the cell edition.

4.3.6 The aircraft type

4.3.6.1 Attributes

An aircraft type is composed by:

- a code,
- a name,
- a category represented by its number.

This information is the necessary and sufficient information for an aircraft type exhaustive description inside LCCR.

In addition, LCCR displays for a given aircraft type:

- the number of flight plan using that aircraft type.

	Description	Category	Flights number
CE00	CHALLENGER CE000/001	1	20
CN35	CN-235/CN235	2	12
CONC	CONCORDE	1	6
CVLT	CANADAIR CL-66/CV-58	1	11
D228	DORNIER 228-100/200	2	26
D328	D328	2	92

Some aircraft types

4.3.6.2 Creation

When LCCR is in modify and insert mode, the end-user can create a new aircraft type by calling the <Insert record> function when the aircraft types list is active (through the <View demand. Aircraft types> function).

When inserted by the end-user, all the attributes of the aircraft type must be filled in (including its code). When finished, the end-user must validate the information through the <Validate> function above the upper frame. After this step, the new aircraft type is created and LCCR exits from the insert mode (the end-user can abort at any time the insertion of the currently created object by calling the <Ignore insert> function): the code of the aircraft type cannot be changed any longer in the future.

4.3.6.3 Modification

When, in modify and insert mode, the end-user wishes to modify the category an already created aircraft type belongs to, she just has to edit the cell corresponding to that attribute: the modification is automatically validated when she quits the cell edition.

4.3.7 The elementary sector

4.3.7.1 Attributes

An elementary sector is composed by:

- a code,
- a list of collapsed sectors which it belongs to (represented by their codes separated by a single space),
- a co-ordination time.

Concerning an elementary sector, when it is selected LCCR displays a list of abilities is displayed in the lower frame.

	Collapsed sectors	Coordination time	Crossing flights number	Average crossing duration	Load cumulative duration (coord.)	Load cumulative overload (coord.)	Capacity cumulative duration	Capacity cumulative overload (coord.)	Load relaxation	Load relaxation %	Load regulated overload (coord.)	Capacity relaxation	Capacity relaxation %	Capacity regulated overload (coord.)
EGTTDTN	EGTTDTY	6	392	10	6377	290	23520	99	0	0	0			
Period / Capacities : EGTDTN														
	Start	End	Capacity						Load					
EGTTDTN	0000	2400	48						13					

An elementary sector

This information is the necessary and sufficient information for an exhaustive elementary sector description inside LCCR.

In addition, LCCR displays some information that we describe bellow.

4.3.7.1.1 Demand additional information

- The “crossing flights number”, which is the number of flight plans crossing that sector (if a flight plans crosses a sector twice non consecutively, it is considered to cross it twice).
- The “average crossing duration”, which is the average crossing time of the flights crossing that sector, not taking into account the co-ordination time of the sector; this value is expressed in minute.
- The “load cumulative duration (coord.)”, which is the sum of all the crossing flights duration including the sector co-ordination time, expressed in minute (this value is called the load demand volume **LDV** in the LCCR reference manual).
- The “load cumulative overload (coord.)”, which is the total number of minute during which the load demand profile exceeds the load limit profile. This value is expressed in minute (this value is called the load demand over volume **LDOV** in the LCCR reference manual).
- The “capacity cumulative duration”, which is the sum of all the crossing flights duration if we considered that each flight plan would cross the sector during **collapsed_sector_capacity_unit** minute (this value is called the capacity demand volume **CDV** in the LCCR reference manual).
- The “capacity cumulative overload (coord.)”, which is the total number of minute during which the capacity demand profile exceeds the capacity limit profile. This value is expressed in minute (this value is called the capacity demand over volume **CDOV** in the LCCR reference manual).

4.3.7.1.2 Regulation additional information

- The “load relaxation”, which is the number of additional units granted, during all the regulation day limited to the sector open periods, to the sector load limit profile during the solving (regulation).
- The “load relaxation”, which is the percentage of additional units granted, during all the regulation day limited to the sector open periods, to the sector load limit profile during the solving (regulation), compared to the minimum non null load during the regulation day.
- The “load regulated overload (coord.)”, which is, after regulation, the total number of minute during which the load regulated profile exceeds the initial load limit profile. This value is expressed in minute (this value is called the load regulated over volume **LROV** in the LCCR reference manual).
- The “capacity relaxation”, which is the number of additional units granted, during all the regulation day limited to the sector open periods, to the sector capacity limit profile during the solving (regulation).

- The “capacity relaxation %”, which is the percentage of additional units granted, during all the regulation day limited to the sector open periods, to the sector capacity limit profile during the solving (regulation), compared to the minimum non null capacity during the regulation day.
- The “capacity regulated overload (coord.)”, which is, after regulation, the total number of minute during which the capacity regulated profile exceeds the initial capacity limit profile. This value is expressed in minute (this value is called the capacity regulated over volume CROV in the LCCR reference manual).

4.3.7.2 Creation

When LCCR is in modify and insert mode, the end-user can create a new elementary sector by calling the <Insert record> function when the demand elementary sectors list is active (through the <View demand.Elementary sectors> function).

When inserted by the end-user, all the attributes of an elementary sector must be filled in. But before that, the end-user must first fill in the information of the lower frame (the abilities of the elementary sector). When finished, she must validate the abilities through the <Validate> function above the lower frame; once the abilities validated, they can still be modified in the future but restrictively. Then, the end-user must fill in the information asked for in the upper frame (including the code of the elementary sector in the row header, as well as the collapsed sectors it belongs to separated by single spaces). When finished, the end-user must validate the information through the <Validate> function above the upper frame. After this step, the new elementary sector is created and LCCR exits from the insert mode (the end-user can abort at any time the insertion of the currently created object by calling the <Ignore insert> function): the code of elementary sector cannot be changed any longer in the future.

4.3.7.2.1 The abilities

Each time the end-user wishes to add an ability to the sector, she has to call the <Insert record> function above the lower frame, specify the start and end times of the period, the capacity and the load of the sector for that period. When she wants to erase an ability from the sector, she just has to call the <Delete record> function above the ability row to delete. Only when the end-user is satisfied with the abilities, she has to call the <Validate> function above the lower frame.

4.3.7.3 Modification

When, in modify mode, the end-user wishes to modify an already created sector, she just has to edit the cell corresponding to the attribute she wants to change: the modification is automatically validated when she quits the cell edition.

4.3.7.3.1 The abilities

Some limitation is imposed on the abilities modification. Indeed, when already created, the end-user must respect its overall open periods. She is allowed to change the abilities of a sector, to insert or delete periods, but at the end of the modifications (when validating), the union of all the periods defined must be equal to the former union.

4.3.8 The collapsed sector

4.3.8.1 Attributes

A collapsed sector is composed by:

- a code,
- a list of elementary sectors that it gathers (represented by their codes separated by a single space),
- a co-ordination time.

Concerning a collapsed sector, when it is selected LCCR displays a list of abilities is displayed in the lower frame.

	Elementary sectors	Coordination time	Crossing flights number	Average crossing duration	Load cumulative duration (coord.)	Load cumulative overload (coord.)	Capacity cumulative duration	Capacity cumulative overload (coord.)	Load relaxation	Load relaxation %	Load regulated overload (coord.)	Capacity relaxation	Capacity relaxation %	Capacity regulated overload (coord.)
EGTTNOR	EGTTGOL EGTTBNH EGTTBNL	6	395	22	11273	1705	23700	302	0	0	0			
Period / Capacities : EGTTNOR														
	Start	End						Capacity	Load					
EGTTNOR	0000	2400						40	13					

A collapsed sector

This information is the necessary and sufficient information for an exhaustive collapsed sector description inside LCCR.

As for the elementary sector, LCCR displays for the collapsed sector some additional information that is built in the same way (we consider the parameter `elementary_sector_capacity_unit` instead of `collapsed_sector_capacity_unit`).

4.3.8.2 Creation

Everything said concerning the elementary sector creation applies to the collapsed sector's, except that the collapsed must be notified the elementary sectors belonging to it and that a collapsed can be inserted only when the demand collapsed sectors list is active (through the <View demand.Collapsed sectors> function).

4.3.8.3 Modification

Everything said concerning the elementary sector is valid for the collapsed sector.

4.4 The lists (editable or not)

LCCR uses much the lists so as to represent the objects. A list is a graphical representation of an array, composed by columns and rows with headers. On each row, the same object is represented. A row is split into cells, as many as columns, plus a header. Each editable list provides a vertical and an horizontal scrollbar if necessary, so that the end-user can view the whole information it contains.

4.4.1 The different lists

4.4.1.1 Layout

All the objects presented can be displayed on the lists. Some lists are editable, some not; some lists present the regulated information, some only the estimated information (demand).

4.4.1.2 Click mechanism

On the sectors (respectively aerodromes) lists displayed in the upper frame, when the end-user clicks with the left mouse button on one row header

(respectively on one cell), LCCR displays some information concerning the object represented by the row (respectively by the cell), in the lower frame. If the end-user clicks on a row header representing a sector with the left mouse button and the <Ctrl> key pressed at the same time, LCCR displays the chart diagram corresponding to the traffic that crosses this sector (see The charts diagrams for more information).

4.4.1.2.1 Special behaviour

This mechanism is also used in two other special cases, even if the list on which it is applied is not in the upper frame.

4.4.1.2.1.1 *On a flight route list*

While viewing a flight route list in the lower frame, when the end-user clicks with the left mouse button on the row header of a sector (elementary or collapsed), LCCR displays, in an outer frame, its information in two split non editable lists. If, moreover, the end-user pressed the <Ctrl> key at the same time, LCCR will issue, in an outer frame, a list presenting the detail concerning that sector (above) and its chart diagram (below).

4.4.1.2.1.2 *On a flight plans list got through the <View flight plans at...> function*

While viewing the list of the flight plans crossing a given sector at a given time (got through the <View flight plans at...> functions above a chart diagram), when the end-user clicks the left mouse button on the row header of a flight plan, LCCR issues, in an outer frame, two non editable lists split representing the detail of that flight plan.

4.4.2 Demand view

This kind of view is activated through the <View demand> menu, in the upper frame. This kind of view only displays the information concerning the demand: nothing about any regulation is displayed.

4.4.3 Regulation view

This kind of view is activated through the <View regulation> menu, in the upper frame: it displays as well the information concerning the demand, as the information concerning the regulation.

4.4.4 The contextual menu

Each list presents a contextual menu: this popup menu is displayed as soon as the end-user clicks the right mouse button anywhere over the list. This contextual menu offers various facilities, enabled or disabled according to the situation.

Actions
Validate
Sort increasing
Sort decreasingy
Delete record
Insert record
Ignore insert
View demand
View summary
Export in outer window

List contextual menu

4.4.4.1 Validate

This function forces LCCR to take into account the graphical modifications performed on the layout of an object. This function is available as soon as the end-user creates a new object through the <Insert record> function, or when she edits the abilities of an object (aerodrome or sector) in the lower frame.

4.4.4.2 Ignore insert

This function enables the end-user to cancel the creation of an object, while the latter is still being created, that is to say, when it has been inserted but not yet validated. In this case, LCCR passes from the insert mode to the modify and insert mode.

4.4.4.3 Sort increasing

This function sorts the corresponding column in a increasing order.

4.4.4.4 Sort decreasing

This function sorts the corresponding column in a decreasing order.

4.4.4.5 Delete record

This function enables the end-user to delete the corresponding object on the row (or the cell for an aerodrome) on which the button has been clicked. It deletes as well the row from all the lists where it appears (except the exported lists).

4.4.4.6 Insert record

This function enables the end-user to create an object of the same type in an editable list. Once this function called, LCCR is in modify mode and it creates a new row in the list from where the function was called (a cell when it handles with aerodromes). As long as the modifications are not validated through the <Validate> function, the graphical modification are not taken into account. Especially for the aerodrome, the flight plan, the sector objects, it is necessary to validate the changes first on the lower frame, and only then on the upper frame.

If the end-user wants to abort the creation of the object, she has to perform the <Ignore insert> action.

4.4.4.7 View regulation/demand

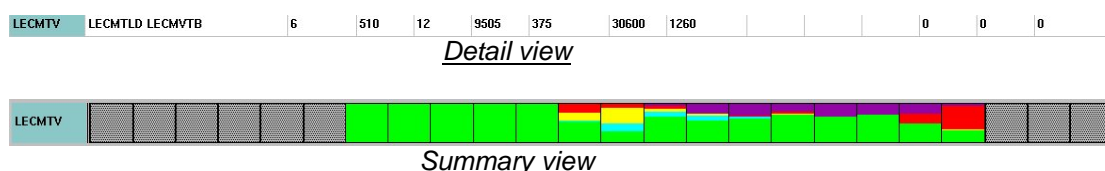
On a sector or a flight plan list, this function enables the end-user to switch from the demand view (activated via the <View demand> functions) to the regulation view (activated via the <View regulation> functions) and inversely. If one row is selected in one table, only the corresponding other row will be created in the other view if the editable list has not been created yet. Of course, this feature is enabled only if one solution is present for the current solution set.

4.4.4.8 View summary/detail

This feature is new and has not been fully tested. Yet, On a sector list and in regulation view, this function enables the end-user to switch from the summary view to the detail view and inversely.

The detail view is the kind of list LCCR displays when the end-user calls one of the <View demand> functions (standard list). However, when in summary view, LCCR does not represent any figure, but it represents for each sector its crossing flight plans delays repartition after regulation, that we call the summary.

Of course, this feature is enabled only if one solution is present for the current solution set and when LCCR is in regulation view.



The various layers are represented in different colours (hard-coded):

- green is used for flight plans having a delay strictly inferior than 15 minutes,
- cyan is used for flight plans having a delay greater or equal than 15 minutes and strictly inferior than 30 minutes,
- yellow is used for flight plans having a delay greater or equal than 30 minutes and strictly inferior than 45 minutes,
- red is used for flight plans having a delay greater or equal than 45 minutes and strictly inferior than 120 minutes,
- purple is used for flight plans having a delay greater or equal than 120 minutes.

4.4.4.9 Export in outer window

This function enables the end-user to create a new window displaying the same list. Nevertheless, this new list is a static copy of the former one: any change in the former one will not be reflected to the newly created. Moreover, this new list cannot be edited at all, nor exported.

4.5 The charts diagrams

LCCR uses these charts diagrams to represent the demand and regulation of the sectors.

4.5.1 What it represents

A chart diagram displays an abscise representing the time, and an ordinate representing the capacity or/and load profiles, i.e. the capacity or/and load

maximum profiles, demand profiles and regulated profiles of a given sector. All the profiles displayed take into account the sector co-ordination time. Note that the profiles displayed represent the solving parameters and not the individual values. In fact, when the end-user chooses to use a global co-ordination time for all the sectors, instead of the individual value, the diagram charts use this global value instead of the individual ones.

4.5.2 The legend

The end-user can display the legend of the diagram, which illustrates the information present.

4.5.3 The scrollbars zoom mechanism

Each chart diagram always presents a vertical and an horizontal scrollbar. These scrollbars present a specific facility, which consists in enabling the end-user to zoom in and out. Indeed, when the end-user clicks on the edge of the accelerator by while pressing the <Shift> key, its size changes and the time scale is updated accordingly. The resize mechanism is centred when pressing both the <Shift> and <Ctrl> keys.



The diagram chart horizontal scrollbar

4.5.4 Demand view

In this view, when the end-user clicks the left mouse button by pressing <Ctrl> at the same time on a sector row header in demand view, the corresponding chart diagram appears in the lower frame. It shows the capacity or/and load demand profiles, as well as the capacity or/and load maximum profile.

4.5.5 Regulation view

In this view, when the end-user clicks the left mouse button by pressing <Ctrl> at the same time on a sector row header in regulation view, the corresponding chart diagram appears in the lower frame. It shows the capacity or/and load demand and regulated profiles, as well as the capacity or/and load maximum profile.

4.5.6 The contextual menu

Each chart diagram presents a contextual menu: this popup menu is displayed as soon as the end-user clicks the right mouse button anywhere except on the time scale over the diagram. This contextual menu offers various facilities, enabled or disabled according to the situation.

Actions
Zoom out
View all range
Show lines
Show legend
Hide layers
Capacity view
Load view
Capacity & load view
Demand
View flights at...
Export in outer window

The diagram chart contextual menu

4.5.6.1 Zoom out

Functions that changes the visible part of the time scale: it doubles it so that the time scale is enlarged.

4.5.6.2 View all range

Functions that shows the time scale from 21:00 PM the day before the regulation, until 03:00 AM the day after the regulation.

4.5.6.3 Show/hide lines

Function that shows or hides the lined marks on the chart.

4.5.6.4 Show/hide legend

Function that shows or hide the legend of the chart diagram.

4.5.6.5 Show/hide layers

Function that shows or hide the graphical layers on the chart diagram in regulation view. When active, LCCR displays in different colours the regulated profiles, according to the delay of the flight plans. Three different layers are displayed. The first one displays the regulated profile due to the flight plans having a delay greater or equal than `limit_layer2`; the second one displays the regulated profile due to the flight plans having a delay greater or equal than `limit_layer1` and strictly less than `limit_layer2`; the last layer shows the whole regulated profile. Remember that the two parameters are settable through the LCCR settings panel (<File.LCCR settings> function, see LCCR settings: <Alt+L>).

4.5.6.6 Capacity view

Function that only displays the capacity profiles. The view mode is capacity.

4.5.6.7 Load View

Function that only displays the load profiles. The view mode is load.

4.5.6.8 Capacity and load view

Function that displays as well the capacity and the load profiles. In this graphical mode, the function <View flights at> is disabled.

4.5.6.9 Demand/Regulation

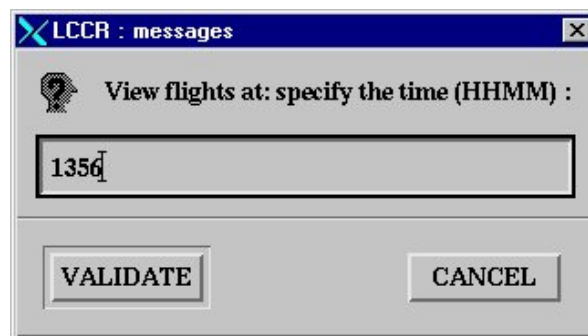
Function that has an impact on the function <View flight plans at> on a chart diagram in regulation view. When the end-user calls the function with “demand”, the flight plans displayed in the function <View flight plans at> will be the demand flight plans (with a null delay, before regulation). In the other case where the mode is “regulation”, <View flight plans at> will consider the regulated flights (after regulation).

4.5.6.10 View flight plans at: <Ctrl> + left mouse button click

This function is disabled when in load and capacity view, so as to avoid ambiguity.

Function that enables the end-user to visualise the list of the flight plans taken into account at a given time in the sector represented by the chart diagram: the non editable list is displayed in an outer window. The end-user is asked to enter this time, and then, LCCR displays a list representing all the flight plans taken into account by the current view mode (capacity or load view modes). Whether the view mode is capacity or load, the list is built accordingly.

This function can also be triggered directly by pressing the <Ctrl> key and by clicking the left mouse button at the same time: in this case, LCCR considers that the time demand is the current cursor time.



<View flight plans at...> function dialog box

LCCR : flights list

Capacity regulated flights list for sector LIMMADS at 1356

	A/C	A/D	D	ETOT	A/D	A	EAT	Stat	Flight type	Linked flight	Delay maximum
AEL2069	B763	MMU	0425	LIMC	1339	E	1/1				180
AFR171 G	A321	LFPG	1250	LIMC	1401	N	1/1				180
AZA050	MD80	LIMC	1350	LEBL	1505	N	1/1				180
AZA068	A321	LIMC	1315	LEMD	1458	N	1/1				180
AZA069	MD80	LEMD	1200	LIMC	1345	N	1/1				180
AZA087	BA46	LEVC	1225	LIMC	1400	N	1/1				180
AZA1303	MD80	LIMC	1350	LIPE	1419	N	1/1				180
AZA1325	AT43	LIMC	1320	LIMP	1358	N	1/1				180
AZA1457	MD80	LIMC	1350	LIPZ	1422	N	1/1				180
AZA1719	MD80	LIMC	1310	LICC	1446	N	1/1				180
AZA1720	MD80	LICC	1150	LIMC	1325	N	1/1				180
AZA241	A321	EGLL	1235	LIML	1414	N	1/1				180
AZA307	A321	LFPG	1300	LIMC	1411	N	1/1				180
AZA390	MD80	LIMC	1340	LFLI	1423	N	1/1				180
AZA466	MD80	LIMC	1305	EDDL	1418	N	1/1				180

CLOSE

<View flight plans at...> function flight plans list outer window

4.5.6.11 Export in outer window

This function enables the end-user to create a new window displaying the same diagram chart. Nevertheless, this new diagram chart is a static copy of the former one: any change in the former one will not be reflected to the newly created. Moreover, the facilities of the new chart are limited.

5 Some global concepts and mechanisms

In this paragraph, we present global concepts and mechanisms that are used in the LCCR prototype.

5.1 The preferences

LCCR uses some preferences that are automatically stored through the different <Save> functions. The name of the file containing the preferences is **preferences.lccr**. These preferences concern the settable parameters and the solving parameters.

5.2 What can be changed in the objects

We sum up here the different attributes that can be changed for the various objects, once the object has been created and validated or loaded. Each time an attribute is modifiable in modify mode, we mark it with a (*).

5.2.1 For a flight plan

- The aircraft type via its code.
- The estimated take off time: when this field is modified, the estimated arrival time as well as the entry and exit times in all the crossed sectors are modified accordingly.
- Its maximum delay allowed (*).

The flight plan cannot be modified through the sectors it crosses.

5.2.2 For an aerodrome

- All the capacities can be changed as well as the periods on which they are applied.

5.2.3 For a category

- Its maximum delay (*).

5.2.4 For an aircraft type

- The category number it belongs to.

5.2.5 For a sector

- Its co-ordination time (*).
- Its abilities but not its open periods (*).

5.3 Up to three solution set at the same time in memory

LCCR can store up to three solution set in memory. To enable the end-user to re-launch the solver without losing the former solution, LCCR offers the opportunity to store each demand and its optional solution (which compose a solution set) in memory. Each solution set stored can be re-displayed, so as to enable regulation comparison. This feature is practical when the end-user wishes to perform little modification on the demand, or simply when she wants to change the solving parameters, but that she wants to keep in memory the former values.

5.4 Four modes

LCCR can run in four different modes, imposing specific edition modes. When the cursor becomes a cross above a list, it means that the corresponding cell under the cursor is not editable.

5.4.1 The modify and insert mode

The first mode corresponds to the data in memory total free edition: the end-user is allowed to change any feature of the objects, unless they were not forecasted to be edited. Moreover, the end-user can delete and create some of these objects.

In this mode, the current solution set is always the modification solution set. LCCR exits from this mode as soon as a solution is present in memory for the current solution set, or that one solution set for storage is used.

5.4.2 The insert mode

This mode corresponds to the data insertion edition: the end-user is allowed to change only the attributes of the object being created. Moreover, the end-user cannot delete or modify other objects. However, it is possible for the end-user to visualise other objects of a different class. As long as LCCR stays in insert mode, the data cannot be saved (through the <File.Save> function), the LCCR settings cannot be changed and the solver cannot be launched.

In this mode, the current solution set is always the modification solution set. LCCR exits from this mode as soon as a the object being created is validated (<Validate> function) or ignored (<Ignore insert> function) when the current list visible is the list from where the object was inserted.

5.4.3 The modify mode

This mode corresponds to a limited edit mode. In this mode, no object can be deleted nor created. Nevertheless, the end-user is allowed to modify certain data that we exhaustively list.

To edit the attribute of an object, the end-user must double-click on the cell representing it, or keep the left mouse button pressed until the cell becomes editable. To quit the edition by validating the modification, press the <Return> key or click the left mouse button outside the cell being edited. To cancel the modifications while still editing the cell, press the <Escape> key.

Here comes the list of the objects editable attributes.

- For a flight plan: its maximum delay authorised.
- For an aerodrome: its capacities.
- For a category: its maximum delay.
- For an aircraft type: nothing.
- For a sector: its co-ordination time, and its abilities.

In this mode, the current solution set is always the modification solution set.

LCCR exits from this mode as soon as a solution is present in memory for the current solution set, or when the current solution set is one of the three solution set for storage.

5.4.4 The blocked mode

This mode corresponds to a non edition mode. In this mode, no object can be deleted nor created, nor modified.

In this mode, the current solution set is either the modification solution set and a solution is present in memory for that set, or it is one of the three solution set for storage.

LCCR exits from this mode as soon as the current solution set is the modification solution set and that no solution is present for that solution set.

5.5 The graphics deleted before search is launched

So as to spare memory, LCCR discards all the objects layouts before a solving is launched. This implies that the end-user loses the current display. We remind the end-user that it is not possible to interact with LCCR during the solving, except for aborting.

5.6 The dialog boxes

We notify the end-user that it is always possible to perform a close or a cancel action on a dialog box, just by pressing the <Escape> key.

5.7 Case sensitivity

LCCR is case sensitive, that is to say that it makes the difference between the lower and the upper case. The end-user should always type considering that feature. For instance, if she wants to edit the collapsed sector EGTTNOR through the <Edit.Collapsed sector> and that she enters <egttnor> instead of <EGGTNOR>, LCCR will not find the corresponding collapsed sector.